ASSESSING THE LIVELIHOOD SYSTEM OF SMALLHOLDER FARM HOUSEHOLDS: POTENTIAL FOR ADOPTION OF IMPROVED FALLOWS AND GREEN MANURE IN ZIMBABWE

By

MAXWELL MUDHARA

A DISSERTATION PRESENTED TO THE GRADUATE SCHOOL
OF THE UNIVERSITY OF FLORIDA IN PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
DOCTOR OF PHILOSOPHY

UNIVERSITY OF FLORIDA

2002

To my sons, Julian and Takudzwa.

ACKNOWLEDGMENTS

I would like to express my hearty thanks to my advisor, Dr. P. E. Hildebrand who was able to keep me focused on the subject and who persevered through the numerous drafts I churned out. Without his dedication to this work, this study would not have been possible. Special thanks also go to Dr. C. Gladwin who was willing to engage in discussions on soil fertility issues in southern Africa. I would also like to thank other members of my supervisory committee, Drs. C. Andrew, and P. K. Nair, for contributing towards the completion of this study and for building my professional and personal growth.

The W. K. Kellogg Foundation, the Government of Zimbabwe and the UF Soils CRSP "Gender and Soil Fertility in Africa" Project funded this study. Victor Cabrera was very helpful in introducing me to Microsoft Visual Basic, which facilitated the work. I would like to express my appreciation to Dr. B. Dzowela who introduced me to the ICRAF agroforestry work at Domboshawa training Center and for facilitating my visit to the agroforestry projects in Maseno, Kenya. I would like to thank members of the Farming Systems Research Team in Mangwende Communal Area, Mr. G. Chiota and Mr. G. Rugara, for all their support during the survey for this work. I am very grateful to the farmers of Mangwende Communal Area who participated in this study. They willingly and openly shared their knowledge and information about their livelihoods. They remained cheerful and welcomed my entourage and me into their homes regardless of the hardships they were going through at that time. The friends I made at the University of

Florida contributed in various ways my completion of this study, my hearty thanks to all of them.

Lastly, but most importantly, I would like to thank my wife, Emma, and my sons, Julian and Takudzwa, for the love and support they gave me and for understanding when we had to be separated for eight months.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Abstract of Dissertation Presented to the Graduate School
of the University of Florida in Partial Fulfillment of the
Requirements for the Degree of Doctor of Philosophy

ASSESSING THE LIVELIHOOD SYSTEM OF SMALLHOLDER FARM HOUSEHOLDS: POTENTIAL FOR ADOPTION OF IMPROVED FALLOWS AND GREEN MANURE IN ZIMBABWE

By

Maxwell Mudhara

August 2002

Chair: Peter E. Hildebrand
Department: Food and Resource Economics

Seventy percent of the population in Zimbabwe resides on the smallholder farms, which are characterized by low levels of income. Low crop yields due to low soil fertility were identified as some of the causes of poor agricultural productivity. The households have low resource levels and operate complex systems in which farming activities are supplemented with non-farming activities. In this dissertation, a household LP model, sensitive to the diversity of smallholder farm households, was developed to simulate their livelihood systems and to use the model to evaluate the potential adoption of improved fallow and green manure technologies.

Mangwende Communal Area of Zimbabwe was selected to take advantage of results from experiments conducted in the area and in adjacent research stations. Data were collected through multiple-visit interviews from ninety-nine randomly selected households and through group interviews. Households, on average, had small farms of

2.6 ha and had two members working fulltime on the farm. Forty percent did not have draft power or cattle manure. Some households were vulnerable to food insecurity.

The model was validated in a participatory manner by a sub-sample of the sample households and, statistically, model output results were compared to survey data. In order to evaluate improved fallows and green manure technologies, data from experiments were added to the model as additional activities. Adoption of new technologies helped households plant more maize and raise their incomes. The benefits that households would derive from the new technologies would depend on their ownership of draft power, available household labor and size of the farm. Households with fewer resources would realize more benefits compared to those who are better endowed.

The potential impact of increases in fertilizer prices was evaluated before and after the introduction of the improved fallows and green manures. Results showed that the new technologies were likely to allow farm incomes to be less vulnerable to fertilizer price increases. Household level characteristics were important in determining the activity levels on the farm after the price increase.

The model developed in this study could be used for evaluating other technologies and policies intended for smallholder farmers. With appropriate modifications on the model, it could be used in other areas in Zimbabwe and in other countries.

CHAPTER 1
INTRODUCTION AND DESCRIPTION OF THE PROBLEM

Background

The challenges facing Zimbabwe are to increase production from the agricultural sector in order to meet the food requirements for its population of 14 million and increase the income levels in the country. The population is growing at 3.1% per annum compared to less that 1% growth in the real value of agricultural production (Central Statistical Office, 1998). Pingali and Binswanger (1998) suggest that with such a discrepancy in the growth rates, a 4% per annum growth rate in agricultural production be required to avert the declining per capita food production. The smallholder-farming sector is an integral part of the solution to increase the country's agricultural production.

Seventy four percent of the population is rural, and 73% of this rural population resides in the smallholder farming sector. The smallholder farming sector comprises one million households in the communal area on 16 million hectares of communally owned land, 52,000 households on 3.3 million hectares of resettled farms, and 8,650 households on privately owned, small farms on 12 million hectares (Muir, 1994). The percentage of the population supported by the smallholder farming sector means that if food security were achieved for this vulnerable sector, the country would have gone a long way towards achieving national food security.

The contribution of smallholder farmers to gross domestic product is small. Therefore, they do not contribute significantly to government financial revenue that could be used for funding food programs. In fact, in many instances the smallholder farmers

need food assistance. The participation of the sector in the country's economy through supply of agricultural commodities to the manufacturing sector is low. Figure 1-1 shows that the value of crops marketed by the smallholder sector was low. Between 1970 and 1980, the smallholder farming sector contributed an average of 6% of the value of marketed crops. This increased to an average of 16% between 1981 and 1996. The trend in percentage contribution also reveals that the contribution of the sector was vulnerable to periodic droughts experienced in 1983, 1987, 1991 and 1995.

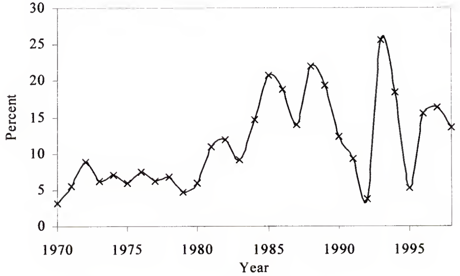

Figure1-1. Percentage contribution of smallholder farmers to value of marketed crops in Zimbabwe

Data Source: Central Statistical Office, 1998;

Crop yields on smallholder farms are low; average maize yields are only 1,300 kg ha^{-1}, ranging from 350 to 2,200 kg ha^{-1}. In comparison, the large-scale commercial farms (LSCF) realize high maize yields of around 5,000 kg ha^{-1} (Farm Management Research Section, 1990). By the early eighties, nearly all the maize planted in Zimbabwe was from hybrid seeds and the status is the same for 2001 (Eicher and Kupfuma, 1997). Since hybrid seeds potentially have high yields, the low yields in smallholder farms are not the

result of poor genetic material. They could partly be attributed to low soil fertility and lack of resources to allow the adoption of other crop management practices that could further raise the yields.

Smallholder farmers confront a myriad of problems and operate complex livelihood systems. Smallholder farmers are one of the social groups identified as being most affected by malnutrition, with the largest number of malnourished people being found in the semi-arid communal areas. Of significance are their multiple objectives, low levels of resources and fragile environmental conditions. The challenge is to determine whether the livelihoods they pursue will be sustainable, under the prevailing, yet changing, economic conditions. This is in accordance with the emerging sustainable livelihoods approach being popularized in development cycles (Scoones, 1998). A livelihood system is sustainable when it can cope with and recover from stress and shocks without undermining the natural resource base (Scoones, 1998).

The areas in which smallholder farmers live have poor soils and harsh climates. These conditions present challenges to the achievement of sustainable livelihoods. Tomich et al. (1995) observed that relative to the rest of the population, smallholder farmers devote more effort and income towards securing food. Female-headed households tend to be among the poorest. Poverty means that they are vulnerable to hunger, disease and are least able to recover from disaster. Their low resource levels mean that their resource allocation is not very flexible. Therefore, their livelihoods are largely unsustainable. Such livelihoods make the households vulnerable to shocks and stresses, and they have to be safeguarded from such eventualities.

Problem Statement

Poverty and food insecurity threaten the livelihoods of smallholder farmers. Infertile soils and application of insufficient fertilizers due to limited resources are some of the most serious threats to increasing food production. Whether farmers can apply chemical fertilizers or their alternatives depends on the economic climate and requisite resources needed for the technology.

Since 1990, the economic climate in Zimbabwe has gone through huge changes, which affected the ability of the smallholder farmers to use inorganic fertilizers, improve the yields of their crops and ultimately increase their incomes. On attaining independence in 1980, the Zimbabwe government redirected development efforts towards the smallholder-farming sector. Government adopted a strategy to increase agricultural production through provision of credit, extension support and improved marketing infrastructure and pricing incentives (Rorhbach, 1986). Indeed the incentives led to increases in production. The incentives, delivered through a regulated economy, made it necessary for the government to intervene in various ways. The government controlled the marketing of agricultural commodities. Commodities could only be marketed through government boards, e.g., the Grain Marketing Board for all field crops except tobacco and cotton. Cotton was marketed through the Cotton Marketing Board, another government board. Government determined producer prices and input prices. To sustain this system, input supplies and marketing of agricultural commodities were subsidized. In 1990, the government adopted a liberalized economic approach to correct distortions caused by the regulated macroeconomic policies pursued in earlier years. The new approach shifted the economy from centralized government control to a free market. In the new economic dispensation, subsidies and price controls were removed, resulting in

an increase in input costs, particularly that of chemical fertilizer. At the same time, the government adopted policies to balance the current account through a reduction of the size of the government work force, thus increasing levels of unemployment and leading to a fall in remittances of cash income to the rural areas from those working in urban areas. The change in the prices of inputs due to the removal of subsidies and price controls led to a decline in smallholder farmers' fertilizer use, thus limiting the prospects of these farmers raising their yields.

Figure 1-2 shows the trend in fertilizer prices from 1980 to 2001. Fertilizer prices increased at a faster rate starting in 1991. Maize prices have kept increasing in response to increase in fertilizer prices, such that in relative terms, the price of fertilizer has decreased over time. This is illustrated by the graph for ratio of fertilizer price to maize producer price in Figure 1-2.

The inherent low fertility of the soils that smallholder farmers cultivate means that the macroeconomic policy changes discussed above could exacerbate the processes of declining soil fertility and land degradation, leading to more poverty and increased food insecurity, and threaten the sustainability of the farmers' livelihoods. Viable alternatives for managing soil fertility are needed urgently. However, the lessons from previous development efforts need to be capitalized. While significant increases in agricultural production occurred after 1980 due to the support given to smallholder farmers, there is evidence that the contribution at farm and regional levels to this growth was heterogeneous. This is analogous to the Green Revolution where some regions of the world were left behind, particularly Sub-Saharan Africa (Conway, 1998). Indeed, in the incentive-driven agricultural revolution of the eighties in Zimbabwe, some farmers were

unable to take advantage of the new incentives. While agro-climatic factors could explain differences in performance at the regional level, differences between households in the same region were due to differences in household level resources, and other factors. This study is concerned with how farmers of diverse characteristics respond to technological options for managing soil fertility and to economic stimuli.

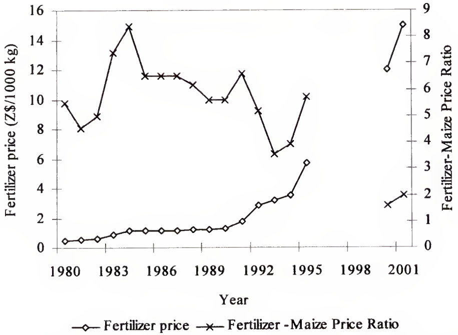

Figure 1-2. Fertilizer price and ratio of fertilizer price to maize producer prices over time.

Source: FAO (2002) and Survey data

Since 1992, research activities to identify viable agroforestry technologies for the smallholder farmers have been intensified in response to the escalating fertilizer prices and the declining production levels in the sector. Improved fallows and green manure are considered promising for improving soil fertility but have not yet been extended to farmers. The potential for adoption of the agroforestry soil fertility technologies in smallholder farming systems has not been sufficiently subjected to *ex-ante* analysis. In

Zimbabwe, activities concerned with improving soil fertility and agroforestry technologies in general are being conducted by the following institutions:

- ICRAF and Department of Research and Specialist Services (DR&SS) conducted research on soil fertility management using agroforestry technologies, including improved fallows, at Domboshawa Training Centre and Makoholi Experiment Station.
- Soil Fertility Network carried out work on the use of multi-purpose trees and leguminous plants. The Network comprises multi-disciplinary research teams from universities and agricultural research centres in Zimbabwe and Malawi.
- DR&SS conducted experiments on inorganic fertilizer use in maize-based systems in Mangwende Communal Area.

Appropriate technologies that farmers can use for improving soil fertility are being developed, but the benefits from such technologies take a long time to reach the farmers, as they may not be targeted to farmers with the characteristics necessary for adoption.

Objectives of the Study

Researchers, extension personnel and other development agents like to know how different kinds of smallholder farmers respond to the introduction of new technologies (or even modifications of existing technologies) and what effect this has on the livelihoods of smallholder farmers. Therefore, there is need to determine, *ex ante,* the impact of the policies and technologies on livelihoods at the household level.

This study seeks to develop a linear programming (LP) model for simulating the livelihoods of smallholder farmers in Mangwende Communal Area, then to use the LP model to determine the potential of households of different resource levels to adopt technologies for managing soil fertility which have not been extended. It also seeks to use the model to determine the likely impact of the technologies on the livelihoods of households that adopt them. The model is also to be used for tracing the effect of economic policies, through their impact on prices of production factors, on the well being

of smallholder farmers. It also seeks to determine how household characteristics influence fertility management under the different economic policy environments. Specific objectives are the following:

Objective 1. To describe the livelihood system of communal area farm households;

Objective 2. To develop a model to simulate the livelihood system of farmers in this communal area;

Objective 3. To use the model to simulate the livelihood strategies of different types of households;

Objective 4. To use the model to determine the potential adoption of agroforestry improved fallow technologies for improving soil fertility by households of different characteristics;

Objective 5. To determine the likely impact of the adoption of the new technologies on the livelihood of the households;

Objective 6. To examine the potential impacts of various alternative policies that might affect soil fertility management practices by smallholder farmers in this study.

Hypotheses

The broad hypothesis of this study is that the resources that households possess determine livelihood strategies they select and the technology they use for managing soil fertility. Given the diversity among households, the potential adoption of new technologies for managing soil fertility varies as well. In addition, the potential for technology adoption can be manipulated though policies. Specific hypotheses are as follows:

Hypothesis 1. Household characteristics, that is, household composition, ownership of draft power and access to non-farm activities, significantly influence fertilizer use.

Hypothesis 2. Draft power owners and households with larger farms and households with more labor are more likely to adopt improved fallows and green manure;

Hypothesis 3. Income levels of farmers who are likely to adopt improved fallows and green manure are likely to increase.

Hypothesis 4. Price policies are likely to be effective in influencing soil fertility management technologies adopted by smallholder farmers.

Agricultural Sector in Zimbabwe

Development efforts in developing countries, where agriculture is the backbone of the economies, place emphasis on increasing agricultural production. The premise of this approach is the need for these countries to transform their economies to a point where the absolute size of the labor force in agriculture starts declining (Tomich et al., 1995). Growth in agricultural production will stimulate other sectors of the economy. As the other sectors grow, labor is demanded away from the agricultural sector. Zimbabwe is no exception to the dominance of the agricultural sector in the economy and the same prescription for development might be appropriate.

Over the period 1985-1998, agriculture contributed an average of 16% to real gross domestic product. It provided income to almost 75% of the population and over 40% of the national exports (Central Statistical Office, 2000). In 1996, GDP per capita was about US$500. The economy is broad based, with agriculture being the most significant sector. In 1998, agriculture, hunting and fishing contributed 18% to the GDP. Other sectors of the economy and their relative contributions to the total GDP are given in Table 1-1. As a significant sector in the national economy, real growth of the economy closely follows the performance of agriculture (Muir, 1994).

Zimbabwe's population was 10.413 millions at the last count in 1992. At an annual growth rate of 3.1%, the population in 2002 could be close to 14 million. In 1990, life expectancy at birth was 58 and 62 for males and females respectively. These are increases of two and five years over similar levels in 1980, for males and females

respectively. However, in 2002, life expectancy levels are expected to have drastically declined due to the effects of HIV/AIDS, estimated to be affecting 25% of the population. This might adversely affect the supply of labor to the agricultural sector as the demography of the population might change.

Table 1-1. Contribution of different sectors to GDP of Zimbabwe in 1998.

Sector	Contribution: Amount at 1990 prices (Z$$10^6$)[a]	Percent
Agriculture, hunting and fishing	4,023	17.53
Mining and Quarrying	899	3.92
Manufacturing	3,886	16.93
Electricity and water	447	1.95
Construction	661	2.88
Finance and Insurance	1,865	8.12
Real Estate	681	2.97
Distribution, Hotels and Restaurants	4,075	17.75
Transport and Communication	2,062	9.00
Public Administration	870	3.79
Education	1,712	7.45
Health	299	1.30
Domestic Services	363	1.58
Other	1,111	4.84

[a]Approximate exchange rate: Z$8 = US$1
Source: Central Statistical Office (2000)

Zimbabwe has a dual farming sector comprising smallholder and large-scale farmers. Smallholder farmers are composed of three sub-sectors, communal area farmers,

resettlement farmers and small-scale commercial farmers. Communal area farmers form the majority. There are about one million communal area farms, 9,000 small-scale commercial farms, and 60,000 resettled farms. In 1997, there were 5,146 large-scale commercial farms in existence (Central Statistical Office, 1998).

The large-scale commercial farms (LSCF) are well endowed with resources. On average, they are 2,200 hectares in size. Fifty-one percent of these farmers are located on the prime land mostly located in Natural Regions (NR)[1] 1, 2 and 3 (Central Statistical Office, 1998). The percentages of the area occupied by each of the mentioned sectors (including the national parks) in each NR are shown in Table 1-2. The large-scale commercial farms are managed as pure business entities, usually being run by farm managers. They also have permanent farm workers. The farms are highly mechanized and have access to credit. Enterprises on the farms are driven by economic considerations. As such, farms in NR 1, 2 and 3 are predominantly engaged in crop production, while those in NR 5 are involved in extensive livestock production. Though they occupy as much as 22% and 29% of the land in NR 4 and 5, respectively, they use most of this land for livestock production, a practice suitable in these regions. When they do crop production in the low potential regions, irrigation is usually used to supplement the little rainfall received.

The Communal Farming Areas of Zimbabwe are located on the least productive area in the country. They occupy about 163,500 km^2 of land, which represents about 42% of all the land in the country. In 1998, the communal areas housed 51% of the population

---

[1] Zimbabwe is divided into five Natural Regions (NR), where NR 1 has the highest agricultural potential, and NR 5 has the lowest potential. NRs are described in Appendix A.

(Central Statistical Office, 1998). Only 26% of the CAs was located in Natural Regions 1, 2 and 3. The rest were in NRs 4 and 5 (Central Statistical Office, 1998).

Table 1-2. Distribution of agricultural sectors by natural region in Zimbabwe (1990).

Farm type/Sector	Percentage by Natural Region					
	1	2	3	4	5	Total
Large-scale commercial	57	64	27	22	29	32
Small-scale commercial	2	4	7	4	1	4
Communal areas	20	22	39	50	46	42
Resettlement area	4	10	17	4	6	8
National parks	17	0	10	20	18	14

Source: Calculated from Central Statistical Office (1998) and Muir (1994)

Small-scale commercial farmers occupy 4% of the country and 56% of them are located in NR 1, 2, and 3 (Central Statistical Office, 1998). Their crop production levels are also low. Between 1990 and 1995, small-scale commercial farmers cultivated an average of 16% of the total area cultivated by the large scale commercial farmers. The resettled farmers consisted of farmers from communal areas resettled on former LSCFs after Zimbabwe's independence in 1980. Sixty-three percent of the resettled farmers are in NR 1, 2 and 3.

Smallholder farm households have low levels of resources in terms of land, capital and labor. In the smallholder sector, the small-scale commercial farmers owned an average of 150 ha per farm. The communal area farmers owned less than 5 ha. Resettled farmers residing in natural regions where crops can be cultivated were allocated 5 ha of arable land. They also accessed communal grazing areas. In contrast, the average large-scale

commercial farms are 2,000 ha (Central Statistical Office, 1998). Smallholder farms are located on land that is mostly of low agricultural potential, spanning the low potential natural regions (NR 3, 4 and 5). This is particularly true of the former Tribal Trust Lands, on which communal areas are located. In the communal areas, the size of land holding depends on the population density in the area. For some farmers the size of the arable fields is less than one hectare and less productive as farmers are encroaching on marginal land. Each household usually possesses some fields at the home-site and other fields that are located some distance from the homestead and garden plots on which vegetables are grown. Households do not have title deeds to the land and thus cannot use the land as security against credit. Grazing land is owned communally.

Over the years, rapid population growth and limited land resources have resulted in overpopulation and deterioration of the land resources (i.e., overgrazing, soil erosion, deforestation and silting of river systems) in smallholder farming areas. Blackie (1994) attributed the decline in soil fertility to poorly protected fields, leading to soil loss.

Crop Production

The crop production system in the smallholder farms is based on summer crops and livestock production. Summer crops are planted during the rainfall season between October and January. The crops that are produced during the wet season are maize, pearl millet, sorghum, cotton, groundnuts, finger millet, sunflower, beans and burley tobacco. Vegetable production and market gardening are also practiced. However, the relative proportions allocated to these crops differ from one communal area to another, e.g., some areas grow cotton or burley tobacco, which may not be found in others. Generally, maize occupies the largest area under crops, except in NR 5. In NR 4, which is not ideal for dry land maize production but drought tolerant crops like pearl millet and sorghum, farmers

still grow maize for most of their cereal requirements. Maize, being the predominant cereal food crop, is marketed when there is a surplus beyond subsistence requirements. The yields that smallholder farmers realize are low compared to those of large-scale commercial farmers. The average yields for maize in large-scale farmers are 5,000 kg ha-1 while they are only 1,300 kg ha^{-1} in the smallholder farms (Farm Management Research Section, 1990). Cotton and sunflower are grown solely as cash crops.

Credit

The Agricultural Finance Corporation (AFC) has traditionally provided credit to smallholder farmers. However, use of credit has declined since 1980. After the liberalization of all agricultural marketing, the commercialized parastatals could no longer collect loan repayments on behalf of AFC. Doing so reduced their capacity to compete with private marketing companies. Therefore, AFC resorted to lending to households who formed themselves into groups. The members of the group are collectively responsible for ensuring that they all repay the loans to the AFC. If any member defaults, then the whole group can not access credit. Households indicated that this is one reason for their not trying to obtain loans from AFC since they say they are burdened with the problems brought by those who are unable to pay. The commercialized agricultural commodity marketing parastatals have also resorted to providing agricultural loans.

Agricultural Produce Marketing

The marketing environment in communal areas has undergone some transformation since1980. The formal marketing environment moved from highly regulated, to liberalized, then to some form of control again.

From 1980 to 1994, the government controlled the marketing of agricultural field crops through the Grain Marketing Board (GMB). The GMB was obliged to buy all produce supplied by households. The government could dictate producer prices and influence the economic viability of different crops. It could also control prices at the consumer level. Producer prices were announced before harvesting, as pre-harvesting prices were preferred to pre-planting prices (Thomson, 1988). Pre-harvesting announced prices allowed the government to better align prices to production cost and expected output. Constant prices were maintained within a season and across space (pan-territorial and pan-seasonal). This neither encouraged households to plant crops in which they had comparative advantage, nor gave incentives to market when prices were highest. Under the same economic system, the government regulated the prices of inputs, apparently, to ensure that farming remained viable.

Due to accumulated budget deficits, distortions in the market and negative impact on household welfare, the government liberalized the marketing system in 1994. This was part of a broader macroeconomic structural adjustment program. Instead of GMB being a monopsony, private companies were allowed to purchase agricultural commodities on the market and the GMB was retained as a buyer of last resort for maintaining a floor price. In addition, the GMB was mandated to maintain a buffer grain reserve to cushion the nation from unanticipated food shortages.

During the mid-eighties, GMB adopted a policy of ensuring that every household was less than 30 kilometers from the nearest GMB buying point. To achieve this objective, the GMB setup a network of authorized buyers. These bought grain at regulated prices, with provision for a marketing margin for the buyers.

The GMB independently determined and announced buying prices, which were fixed during the marketing season. The prices were only reviewed annually. Private buyers also independently determined prices at which to purchase commodities from communal households. Over the years, prices offered by private buyers have been lower than those offered by the GMB. Unlike the GMB, private buyers varied their prices within the season and over space.

Bureaucratic procedures in the GMB mean that it takes a minimum of two weeks for it to make payments for grain delivered to its depots. In contrast, private buyers pay cash on delivery. At most times, households are desperate for cash. Therefore, they are willing to forego the higher prices offered by GMB for the spot prices paid by private buyers.

The GMB grades all the grain delivered to it. Since transporters charge households per truckload, households who want to sell small quantities have to team up with other households to fill a truck. When teaming up, the grade of all the grain in the truck might be affected by one household's grain. Since payment is based on the grade that the grain achieves, households prefer not to share transport when delivering to GMB. With private buyers, each bag is graded by visual assessment and individually. This eliminates the possibility of the grade of one's grain being downgraded due to being mixed with a fellow household's low-grade grains.

Moisture content is an important grading element for GMB since it has to store grain for long periods as part of the buffer stock. Households have no means of determining the recommended 12.5% moisture content of grain, so they use crude methods for estimating moisture content. At times such crude methods do not work. For example, in

1997, due to late rains, most households delivered maize with a moisture content exceeding 12.5%. The GMB rejected their grain. Farmers transported the grain back to the homestead, dried it and re-transported to GMB. To encourage households to deliver grain early to the GMB, the limit on the moisture content was relaxed in 2001. GMB also considers the percentage of impurities and level of grain development and color in determining the grade. Farmers are of the opinion that the GMB intentionally downgrades maize delivered by smallholder households. Therefore, in taking grain to GMB, there is a chance that one might have grain rejected and end up paying twice as much to transport the grain to and from the GMB. Thus to avoid this risk, some households sell to private buyers who are not particular about the moisture content.

Non-cropping Activities

Some farmers engage in non-cropping activities for secondary sources of cash income, e.g., selling home brewed beer, casual work, sale of their craft work, brick making and contract building. Cash remitted from family members working away from the homestead is an important source of cash in the system.

Organization of the Dissertation

The dissertation is organized into eight chapters. Chapter 1 presents the introduction, including the problem statement, objectives and hypotheses. In Chapter 2, relevant literature is reviewed. The third chapter presents the methodology of the dissertation while the fourth chapter describes the livelihood system of the smallholder farmers in the study area, Chapter 5 describes the model developed for the smallholder farmers, and the validation of the model. In Chapter 6, the potential adoption of *Sesbania sesban* and pigeon pea improved fallows for managing soil fertility technologies is assessed while

Chapter 7 assesses the potential adoption of cowpea green manure. A summary, conclusions and policy recommendations are presented in the Chapter 8.

CHAPTER 2
REVIEW OF LITERATURE

This section reviews literature that supports the subject, approach and methods to be adopted in this study. Smallholder farmers are defined and contrasted to large-scale farmers. Then recent developments regarding to household models and linear programming are presented. The contribution of institutions to smallholder farmer behavior and outcomes of their livelihoods is also discussed. The topical issue of sustainable livelihoods is introduced with respect to how it can be handled through LP models.

Defining Smallholder Farmers

Smallholder farmers have limited resource endowments, i.e., land, labor and capital. Until recently, land was not a critical constraint in sub-Saharan Africa. In fact, production was increased through opening up new land. In some areas soil fertility was maintained by shifting the area on which crops were planted, to allow fertility to regenerate (Alvord, undated). Increases in population means that shifting cultivation can no longer be practiced. Land has become a limiting resource. Yet, this land is of poor quality (Hildebrand, 1986). Capital, particularly cash is limiting. Farmers lack fixed capital for use as collateral and consequently, their access to credit is constrained. Since they do not have collateral, they are charged high interest rates on loans. The farmers largely depend on family labor for undertaking agricultural activities. Although they operate small pieces of land, smallholder farmers usually experience shortages of labor at critical times during the year. Households at times supplement income by taking part in off-farm

activities. This tends to take some of the available labor away from farming activities, leaving some farmers vulnerable to labor shortages.

Smallholder farmers take the farm as first a home rather than a business, where decisions are made from the point of view of the home with the well being of the home and family overriding profit considerations. Households engage in diverse activities, such that they tend to have limited time for management of any particular activity (Hildebrand, 1986). In addition, low education levels and limited access to information tend to reduce the quality of management on small farms. Access to services such as information, marketing, transportation, storage and processing, is limited (Hildebrand, 1986). These factors have implications on the technologies that smallholder farmers use and their overall productivity.

The household level is the social and economic unit through which smallholder farms manage resources and organize consumption and so should be the focal point for development (Netting, 1993; Timmer et al., 1983; Hilbebrand, 1986, de Koeijer et al., 1999, Ruben et al., 1998). According to De Koeijer et al. (1999, p 34), the farm is also the level at which "the psycho-sociological, agro-economic and agro-ecological disciplines interact most profoundly". External factors like agro-ecological and socioeconomic environments interact and influence households (Ruben et al., 1998).

The agro-ecological environment determines the potential agricultural activities households could engage in. On the other hand, the socioeconomic environment determines the activities that households select. The socioeconomic environment is determined by the macro-economic policies, e.g., prices, institutions, laws. The task of understanding how the livelihood strategies of households are influenced by the

socioeconomic and agro-ecological circumstances around them is made easier by the fact that farmers have been observed to be rational in their behavior. Schultz (1964) argued for the rationality of smallholder farmers. He stated that: "There are comparatively few significant inefficiencies in the allocation of the factors of production in traditional agriculture" (Schultz, 1964, p. 37). This justifies the use of economic models that work with the assumption that households are economically rational. Further to this, Ellis (1993) noted that peasant farmers maximize profits. Ellis' concept of profit maximization was not the same as that used in firm profit. "Profit maximization in the context of smallholder farmers does not require the existence of profit in the form of a sum of money. What it requires is for there to be adjustment of inputs or outputs that could give the household a higher net income, whether measured in money or physical terms. This applies equally to a near subsistence household as to a fully monetized one" Ellis (1993, p. 64). Methods that seek to understand the behavior of farm households while assuming rational behavior by farmers need to measure "profits" that accrue as both cash and physical outcomes.

Smallholder farmers have multiple objectives, such as increasing cash for buying consumer goods and achieving food security (Ellis, 1993; Hildebrand, 1986). Some of the objectives are complimentary yet others are competitive. The multiple objectives of smallholder farmers mean that changes in economic stimuli result in, not one but many responses (Ellis, 1993). The heterogeneity, autonomy and self-determination of farmers make their responses to similar stimuli different (Netting, 1993; Ellis, 1993). To capture all the responses of smallholder farmers requires an understanding of their diversity.

The objectives ascribed to smallholder farmers depend on the activities that they engage in, the amount of resources they have for meeting the set objectives and the entitlements they can draw upon. Decisions are made with limited resources, i.e., land, labor and capital. Since decisions are made from the point of view of the home where the well being of the home and family override profit considerations, satisfaction of subsistence requirements is prioritized over monetary income.

Chayanov described farmers with little or no access to markets, abundant land, and sparse population, who reallocated their land periodically and only produced enough for their needs while minimizing labor effort (Thorner et al., 1986). Such farmers are now rare. Netting (1993) defined smallholder farmers as rural cultivators practicing intensive, permanent diversified agriculture on relatively small land areas. While they produce some of their food requirements, they interact with the market for other requirements. Excess labor is often engaged in off-farm activities or production for the market. The activities household undertake are for the common good of the members. Household members act together to make rational decisions by managing and allocating labor, knowledge and leadership, tools, land and capital while recognizing the climate, resource constraints, markets and institutions (Netting, 1993). The farming systems are complex and present a challenge for modeling.

Assessing the Impact of Economic Changes on Smallholder Farms

Ellis (1992) argued that since smallholder farmers produce some of their subsistence requirements, they could disengage from the market. State actions perceived as disadvantageous can be avoided. Netting (1993) also observed that smallholder farmers, by various ways, are able to remain on the farm when faced with unfavorable economic circumstances. Smallholder farmers interact with markets for goods and services, which

are outside their system. Prices in these markets, in part, determine the level of surplus produced for the market. For example, in Nigeria, smallholder farmers 're-intensified' agriculture to maintain and even expand the amount of surplus food they could sell when faced with declining land availability and soil fertility (Netting, 1993). Using the same analogy, smallholder farmers in Zimbabwe faced with an adverse economic climate, due to the structural adjustment program, might also be expected to respond in a manner that might even result in their cash income increasing or their food security status improving.

Livelihood Systems of Smallholder Farm Households

A livelihood system encompasses all the activities that are available to households to engage themselves in for their survival, today and in the future (Chambers and Conway, 1992). They are complex and diverse sets of economic, social and physical strategies undertaken by farmers through capabilities, activities, assets and entitlements (UNDP, 2000; Scoones, 1998). Development professionals are concerned with whether a livelihood system is sustainable. Given the myriad of problems confronting the poor, a broader understanding of the requirements of human life, particularly for those in poverty, is required before solutions can be devised. This is the sustainable livelihoods approach to development. Sustainable livelihoods can then be taken to be non-declining welfare over time. A livelihood is sustainable when it can cope with and recover from stress and shocks, while not undermining the natural resource base (Scoones, 1998). This implies sustainable use of resources. In pursuing sustainable use of resources, present day needs of deprived people should not be overlooked (Anand and Sen, 1996). In addition, preserving the productive capacity through sustainable development does not necessarily mean leaving the world as the present generation found it, in every detail. In fact, it implies leaving the same opportunities for future generations to make a living.

Resources can be substituted for each other and it may be noted that future generations might have different tastes from those of present generations. Such tastes may well require different resources.

Livelihood strategies are based on the assets that households have access to, which include:

- Natural or biological assets, e.g., land, water, common-property resources, flora, fauna;
- Social and political, i.e., community, family, social networks;
- Human, i.e., knowledge, skills, encompassing available labor;
- Physical, i.e., roads, markets, clinics, schools, bridges (UNDP, 2000).

Entitlements are "the set of alternative commodity bundles that a person can command in a society using the totality of rights and opportunities that he or she faces" (Thomson and Metz, 1977; p. 8). They allow one to understand the extent to which assets could be used in the livelihoods of households. Sen (1985) noted that entitlements could be obtained from four sources, i.e., trade, production, own labor and inheritance and transfer-based entitlements. Trade-based entitlements allow individuals to exchange commodities or cash for food and other needs. Production-based entitlements arise from ownership of one's production. Own-labor entitlement arises from the sale of one's labor. Wages from the sale of the labor can be paid as cash or in kind. Inheritance and transfer entitlements refer to the right to own what is willingly given by others as remittances, gifts or bequests, as well as transfers from the state such as social security, pensions and food distributions (Thomson and Metz, 1977). The various sources of the entitlements allow livelihoods to be fulfilled in many ways. A disturbance to the entitlements that a household depends on threatens its livelihood.

Household Models and Linear Programming (LP)

Linear programming (LP) models are mathematically based models of optimization. In the models, a linear objective function is maximized or minimized subject to linear inequality constraints. LP models have been used extensively to formulate farm plans (Hazell and Norton, 1986). Recently, they have also been used to simulate the strategies that farmers adopt and to predict the decisions that they might take in case of changes in policy, technology or resources.

Becker (1965) introduced the new household economics theory that considers households as unified units of production and consumption. Household modeling in which households have one utility function, are appropriate for smallholder farmers. In the new household economics theory, households maximize utility subject to a resource and time constraint. Case studies have used household models (Singh et al., 1986, Ellis, 1993, and Tibaijuka, 1994, Hedden-Dunkhorst, 1992, Litow, 2000; Sullivan, 2000; Cabrera, 1999).

Ellis (1993) observed that, in reality, smallholder farmers maximize "profits" subject to tradeoff with other goals, resource constraints and performance of markets. Further, he noted that the profits do not have to be in the form of money. Adjustment of inputs and outputs should give the household a higher net income. In this case, profit can be interpreted as end of year cash (after taking care of home consumption). If farmers are rational and maximize cash income, they should also respond positively to economic stimuli. Hypotheses can be made on their response to economic policies. If the thesis that smallholder farmers are rational and maximize cash incomes, subject to fulfilling subsistence requirements, were accepted, the farmers would be expected to respond positively to economic stimuli and hypotheses about their response to economic policies

can then be made. Economic variables in LP models, e.g., prices, can be adjusted to determine how farmers respond.

Hazell and Norton (1986) formulated an LP model, where a household maximizes income subject to household resource constraints, of the form:

Maximize: $Z = \sum_j c_j X_j$

Subject to: $\sum_j a_{ij} X_j \leq b_i$ for all i

$X_j \geq 0$

Where: Z = objective function,

$X_j = j^{th}$ production activity of the farm, e.g. Maize, cotton, cattle,

c_j = forecast gross margin of X_j,

a_{ij} = the amount of a of input i needed to operate activity j on a unit of a resource, e.g., a hectare of land

b_i = available supply of the resource i,

An LP model is organized as a tableau (Figure 2-1). The tableau consists of inputs, activities, constraints and the objective function. The inputs section has a list of the inputs needed for all activities. All the inputs listed are not necessarily used by all activities. Activities are represented as columns. They account for the different production techniques through the input-output coefficients. For each activity, the coefficients are linear and constant. In the tableau, the constraints vector, often called the right hand side (RHS), consists of the inputs or resources available to the farmer. There is also an objective function to be maximized or minimized in the model.

LP models can handle multiple crop activities. Effects of changes in decisions on the various crops can be determined (Singh and Janakiram, 1986). Consumption

requirements can be incorporated into the model as constraints. This makes LP models ideal for smallholder farmers who have to meet some minimum subsistence food requirements. Separate activities compete for scarce resources in the model.

	Activity Levels					Net Revenue
Inputs List of inputs needed for all activities. Not all activities require all the inputs	**Crop activities**: Input-output Coefficients				≤ or ≥ or =	**Constraints** Inputs or resources available to the farmer, Also consumption requirements.
	a_{11}					
		$a_{i(j-1)}$				
			a_{ij}			
				$A_{(i+1)j}$		
	The coefficients indicate the amount *a* of an input *i* needed to operate activity *j* on a unit, e.g., unit of land. The coefficients are linear and constant.					

Figure 2-1. Structural Form of the LP model

Models can be constructed to reflect the specific circumstances of each farm. Working with average households has the same weakness as aggregating activities. G-Egziabher (1995) used an LP model on one type of average farmer in Ethiopia. This failure to account for diversity in smallholder households was a major weakness of his study. No variation between households was included in the model. One set of recommendations was made for all the farmers in the area, making the recommendations unrealistic. The diversity between households makes it mandatory that recommendations be sensitive to the diversity (Litow, 2000; Sullivan, 2000; Cabrera, 1999).

LP models allow the basic primal and dual problems to be specified. The dual problem is the other side of the maximization problem stated above. The dual problem minimizes the cost of achieving a given outcome. Dual variables give the marginal values of each constraining resource. Marginal values, the imputed values of each resource, are obtained by solving the following minimization problem:

Minimize: $\sum_{j} b_i u_j$

Subject to: $\sum_{j} a_{ij} u_j \geq c_i$ for all i

$u_j \geq 0$

Where: u_j is the marginal cost of each input.

LP models normally automatically give the results of the dual problems. The solution to the dual problem provides shadow prices, reflecting the increase in net revenue from a unit increase in a constrained input. These implicit prices allocate the total net revenue produced by the optimal solution among the inputs that are fully utilized. Shadow prices from dual solutions provide important insight into scarcity values of the inputs available in fixed or partially fixed supply at the farm level and the impact of increasing the availability of the input by one unit. Surplus inputs will not result in a change in net revenue when more are added. Their shadow price is zero. This valuable information can be used for making appropriate decisions and policies to enhance the livelihoods of smallholder farmers.

Effects of technology and changes in market variables on the objective function can be traced in the LP model. The model gives different combinations and levels of activities in the solution. Decisions on allocation of expenditure to different goods (including farm goods for own consumption and leisure) and the allocation of fixed and variable inputs to different production activities in the short run can be incorporated. In any production cycle, a household objective function can be imposed subject to given constraints. LP models are flexible to changes in assumptions, technical coefficients and activities in the farming system. The marginal effects of such changes can also be pursued.

In reality, farmers often consider several aspects of their welfare when making these decisions (Sen, 1985). This attribute can be addressed in LP models since profit maximization does not need to be the only goal. Other objectives like minimizing labor use can also be accommodated. Multiple objectives such as maximizing revenue after satisfying subsistence requirements can be incorporated in the model.

For each type of household, the area allocated to different crops across different seasons and technologies used are given as a solution in the LP model. A solution corresponds to a given context. A context describes the circumstances that the farmers take as given, e.g., the markets, climate, prices, and foreign exchange rate. Changing the context under which the LP model is constructed results in changes in the combination of activities, hence the surplus mix and the income.

Crops or crop techniques that might be used by farmers, but which they currently do not use can be introduced into the tableau (Timmer et al., 1983 and Bade et al., 1996). Activities are added to existing crop and input activities to assess the likely reaction of farmers when presented with new technologies. Sicular (1986) included a number of activities not observed on model farms, but had previously been used by them or their neighbors.

Sustainable Livelihoods

The sustainable livelihoods approach is gaining prominence in development (Scoones, 1998). There are five components, i.e., contexts, resources, institutions, livelihood strategies and outcomes (Ashley and Carney, 1999 and Scoones, 1998). They include the policy environment, trends, politics, demography, climate shocks, trends, and seasonality. These factors determine access to assets used for achieving a livelihood. Shocks are unpredicted, short-term changes in factors that determine livelihoods. These could be

individual shocks such as illness or death of a family member, natural shocks such as a pest or crop disease, economic shocks such as currency devaluation, price changes or, a political conflict such as war. An LP model has to be specific within a given context. The context determines the feasible activities.

Livelihood resources include human capital, social capital, natural capital, and economic and financial capital. People interact with some institutional setting that determines the level of government and private sector participation. Institutions are in the form of laws, policies, and culture. Livelihood strategies are the activities chosen in the LP in response to a set of contexts, resources and institutions. Scoones (1998) suggested that a strategy could be intensifying agricultural production, diversification or migration. The strategies lead to outcomes such as increased income, better well being, reduced vulnerability, improved food security and more sustainable use of the natural resources.

LP models account for segments in sustainable livelihoods framework. In LP models, resources levels are constraints, e.g., the total quantity of land available to the household. To handle the effects of human capital on the livelihood strategies that households can choose, the gender of the workforce and the size of the household can be incorporated in the LP model. Changing the levels of human resources available changes the decisions made by the household. The technologies that a household can use require a certain level of skills and knowledge. Only those technologies whose level of complexity is commensurate with the skills found in a household can be included in the model for the household. The technologies available to the household have a bearing on the output of a given activity. In turn, the level of output determines the ability of the household to meet

subsistence requirements and subsequently, the net revenue that the household can realize.

Financial capital includes the stocks in the form of savings and transfers. The transfers are usually remittances from members of the family. They could also be pensions that are regularly received. In the LP, all financial resources can be pooled into one constraint or can be handled separately as individual constraints. Financial requirements of activities are entered as parameters.

Social capital, e.g., social claims obtained through social network, affiliations, associations, can be relied upon at different times to fulfill livelihood systems. Quantifiable social capital such as remittances or reciprocal labor or other benefits can be included in an LP model as resource constraints. When social capital is measured qualitatively, it sets the context and conditions in which the household operates.

Beyond the household, are communities with common property, institutions and laws for sharing, monitoring and protecting resources. They influence the behavior of households and the activities they can undertake. Institutions and organizations define the structures and processes through which sustainable livelihoods are achieved. Institutions entail regularized practices structured by rules and norms of society, persistently and widely used. In addition, a culture defines the acceptable behavior of community members. Institutions can be formal or informal, e.g., tenure arrangements, labor sharing mechanisms, market network and credit sources. The institutional setting has to be understood so that opportunities and limitations they present can be recognized in the LP models.

Physical capital consists of infrastructure such as roads and schools that contributes to the fulfillment of livelihoods. Roads are used for accessing health centers or transporting produce and inputs to or from the market. With poor roads, households face difficulties in marketing their produce. Their livelihoods are constrained. Schools enhance the quality of household human capital and their long-term prospects of getting more income. Physical capital cannot be entered directly in the LP model. It defines the context of the model in terms of the activities that are feasible in the area. In addition, the gross margin per unit, say of land, depends on the opportunities open to the household for selling produce. Without a market, prices for an output are low. Consequently, an activity has low gross margin and is unlikely to be included in the model solution unless it produces a staple product needed for survival.

The next section discusses strategies that households adapt in the face of shocks. It also looks at how the livelihood strategies can be accommodated in LP models.

Shocks

Shocks determine whether the old set of livelihood strategies remains feasible and optimal or whether the concerned households become vulnerable. An example of a shock can be a devaluation of a country's currency, a death of a productive member within the household, or a sudden change in the price of an input or output. In an LP model, the shock changes the resources available to the household or the gross margins of the activities that the household could engage in. A new solution will be generated by the LP model once the constraints or coefficients are changed. Under the new conditions facing the household, a new solution becomes feasible.

Scoones (1998) suggested that the historical approach should be an integral part of studying sustainable livelihoods. Experiences that households had during previous

shocks have to be taken into account. Strategies change as the composition of the household changes over time or through changes in the social and/or economic circumstances around a household (Sullivan, 2000). LP models can accommodate several seasons or even years and changes in income can be pursued as an aggregate or in each season or year. Changes in composition and the effect on labor bottlenecks can be accounted for. Nevertheless, the historical analysis allows previous experiences to be used for building LP models that truly reflect what is feasible for the household. The historical and LP model approaches can augment each other.

Well-being

Livelihoods are sustainable when welfare is not declining over time (Anand and Sen, 1996). Welfare is a broad term encompassing various aspects of livelihoods. Not surprisingly, Anand and Sen noted that welfare could also be defined as non-declining income, consumption and capital stock. Welfare is analogous to the income that, according to Ellis (1993), was maximized by smallholder farmers, i.e., income measured in physical and monetary terms. The higher the average income of a country, the more likely it is to have higher average life expectancy, lower infant and child mortality rates, higher literacy (Anand and Sen (1996). Household income can indicate the level of well being in a household. LP models are concerned with household resources, activities and outcomes and are particularly effective at measuring the changes in income brought about by changes in strategies in the household. In this respect, LP models are indirectly able to measure the change in some aspects of well being of households' livelihoods.

LP models give two pointers with respect to the income indicator. First, they directly assess the impact of a change in the combination of livelihood strategies it adopts on household income. Second, they indicate the effects on employment or engagement of

labor within the household. In addition, the abundance or shortage of labor can also be identified. The labor constraint in the dual solution indicates the impact of further increases in labor available to the household could have on income. The LP model can be used for determining whether household members can engage in off-farm activities or wage labor. The existence of off-farm opportunities and the limit on the participation of members have to be specified before hand in the LP model.

Institutions

In understanding the ability or otherwise of households to adopt certain technologies, there is need to take account of the institutions that smallholder farmers interact with and the impact of that interaction. Institutions are norms, rules and organizations. Rules encompass land tenure systems, marketing systems, research and extension. Customs define the manner in which farmers interaction with external bodies, i.e., the rules that define one's behavior or conduct.

The need or relevance of rules is evident when the issue of "tragedy of the commons" is considered. A typical example of "tragedy of the commons" is one where smallholder farmers have communally owned grazing pastures. They do not have incentives to improve their grazing pastures. Everyone wants to increase his or her herd size, leading to overgrazing.

Rondinelli (1979, p 41) suggested that smallholder farmers are largely poor since "they lack access to public and private institutions that have the resources needed to increase productivity and thereby raise incomes." The role of institutions was illustrated in Asia where some farmers did not realize improvements in their lives following the Green Revolution due to inappropriate institutions (Rondinelli, 1979).

Wolmer (1997) defined institutions as encompassing marriage systems, land tenure, markets, labor, manure exchange, draught power sharing arrangements, and cultural prohibitions on certain types of works. While this is an important exposition of the rules, it excludes the organizational institutions that affect the well being of smallholder farmers such as extension, research and training. Without them, one cannot talk about institutions serving smallholder farmers at all.

North (1991) defined institutions as humanly devised constraints that structure political, economic and social interactions. The constraints can be informal e.g., taboos, customs, traditions, and formal, e.g., constitutions, laws, and property rights. Customs create order and reduce uncertainty in the activities between beings. Rondinelli observes that organizations need to be compatible with the rural traditional practices, customs and behavior. The bottom line is that the two, customs and organizations, require each other to be effective. The organizations need some given customs into which to fit, while the customs are of no value if they cannot facilitate the entry and development of organizations bringing services to smallholder farmers. Failure of compatibility between organizations and customs may lead to alienation of farmers. The institutions servicing smallholder farmers need to be highly adaptable to the conditions in rural areas.

The institutions that farmers require depend on the extent to which they are integrated into the market. Subsistence farmers do not have many interactions with the world outside the household. Therefore, they only need minimum institutions. With increased interaction with the market, exchanges are conducted over long distances. The possibility of default by some participants rises. Transaction costs also rise. Yet, exchanges over distances can increase specialization leading to increased productivity. Institutions define

and regulate the manner in which transactions are conducted and fulfilled and are required when exchanges are conducted over long distances.

Induced Innovation Model

According to the induced innovation model, innovations that use less scarce or expensive resources are adopted (Ruttan and Hayami, 1984; Pingali and Binswanger, 1998). The individual shifts from one technology to the other, depending on the relative factor scarcities reflected by factor prices. As population density increases, land becomes scarce and its use becomes more intensive. Consequently, technologies that increase the productivity of land are brought into use, e.g., fertilizer and high yielding varieties. Pingali and Binswanger (1998) proposed that, as farming intensifies, the progression of technologies adopted for improving soil fertility begins with fallow then to use of manure in garden plots, to manure on fields then to green manure. Lastly, use of fertilizer is introduced. Fertilizers are used when farmers move from fallow systems into continuous cropping. When the price of fertilizers increases relative to the prices of other fertility inputs, farmers might resort to the technologies they had used before adopting fertilizers. This could lead to a fall in yields, leading to have serious consequences for attainment of food security.

Agroforestry and Green Manuring Technologies for Smallholder Farms

Agro-forestry is a collective name of land use systems and technologies where perennial woody species are deliberately used on the same land-management units as agricultural crops and/or animals, in some form of spatial arrangement or temporal sequence. There are both ecological and economical interactions between the different components (Nair, 1989 and Hoekstra, 1985). Improved fallows are a form of agroforestry where species are planted as part of a crop-fallow rotation with the primary

purpose of fixing nitrogen. For smallholder farmers the question has been whether land on which to establish the improved fallows is available for the technology to be adopted. However, natural fallows have been observed on very small farms of less than one hectare, proving that fallows possibly have a role to play in these systems (Sanchez, 1999). Surveys conducted in Zimbabwe have shown that there was fallow land that could be exploited for agroforestry soil fertility technologies in the smallholder farming system (Kamau, 1989).

Assessment of potential adoption of agroforestry technologies is challenging because of the complexity of the technology. It has many components, each with different developmental cycles, multiple interactions, variable management over time, tangible and intangible outputs and strong interaction with the socio-political environment. The objectives of farmers need to be taken into consideration so that their well being is not compromised when they adopt the new technologies. Smallholder farmers produce and conduct activities such as crops, livestock, trees, processing activities, off-farm employment. The activities are implemented in a mixed and interactive manner. Households pursue many activities to diversify, reduce risks, and use scarce resources in the most rewarding options to achieve its multiple objectives. It is essential to understand how farmers organise, allocate resources and manage all their activities to arrive at the economic rationale of their decisions.

Green manuring species are also deliberately planted in a crop-crop rotation to capitalize on the nitrogen fixed by the legume green manure crop. This is an ancient practice whose use had declined due to use of chemical fertilizers. Green manuring had the potential to

contribute atmospheric N to the system. Organic N can also increase, resulting in improved soil structure, water infiltration capacity and water holding capacity (Wivstad, 1997).

Research work has indicated that there is potential to increase yields from the use of these technologies in Zimbabwe. The experiments were reported in various reports (Mafongoya and Dzowela, 1999; Mafongoya and Dzowela, 1998, Dzowela, 1993 and Dzowela, 1992). Chibudu (1998) reported improved fallow trials conducted in Mangwende Communal area with Sesbania Sesban. Similar experiences were reported in Zambia (Kwesiga et al., 1992)

The potential of legumes as green manures has been a subject of interest in Zimbabwe (Hikwa and Waddington, 1998; Mapfumo at al., 1998; Muza et al., 1998; Gladwin et al., 1997)). Chibudu (1998) reported on the results of work conducted with cowpeas, and other legumes in Mangwende Communal Area. Gladwin et al. (1997) specifically raise issues about how to make women farmers more accessible to organic fertilizers.

The next chapter presents the methodology used for conducting this study.

CHAPTER 3
METHODOLOGY

This section discusses how the research for this study was conducted. It describes the study area and sampling procedures followed. In addition, the type of data collected and data transformation are discussed. The models to be used on the data are presented.

Description of the Survey Area

The survey for this study was conducted in Mangwende Communal Area (CA) (lying between 17° 22' and 17° 56' S and between 31° 31' and 32° 09' E), in Mashonaland East Province of Zimbabwe. The CA lies in the north east of the country, some 90 km from Harare, the capital city of Zimbabwe. It lies in NR 2 and has a mean annual rainfall between 800 and 950 mm. The bulk of the rainfall in summer comes between the end of October and the end of March. Periods of heavy rainfall occur during the season. These periods lead to considerable soil and nutrient losses accompanied by occasional crop damage and water logging of gardens and low-lying fields. The predominant soil in the area is derived from granite parent materials. Therefore, the soils have low inherent fertility and require high levels of external inputs to improve their level of fertility.

Infrastructure

The administrative center of the area is Murewa Growth Point, about 40 km from the furthest point in the communal area. Besides being the site of the district offices, Murewa also has supermarkets, hardware shops, and three banks.

Murewa Growth Point is located along the highway from Harare to Nyamapanda, on the border with Mozambique. All-weather highways also link Murewa to the provincial

capital, Marondera and Uzumba-Maramba, a district in the northwest. Transport is a major problem for smallholder farmers during marketing of crops and causes delays in the delivery of inputs because of the poor feeder road network. Tarred roads in the CA only offer an advantage to farmers who live along them. Feeder roads running from the main tarred roads into the hinterland are poorly maintained such that they give problems during the rainy season. Most transporters are unwilling to use poor roads. Several private transporters operate in the area and transport produce to Harare or Murewa Growth Point. Public buses also transport horticultural produce to the urban centers. However, these are not adequate. A Grain Marketing Board (GMB) depot is located at Murewa Growth Point. Cotton Marketing Board (CMB) has a sub-depot in the CA. In 1998, a milk collection point was set up in Musami Ward within the CA. Consequently, farmers started to diversify into milk production. There are two general hospitals in the area, which are supported by several clinics and village health workers.

Crop Production

Crop production is the major activity sustaining the livelihoods of the farm households in Mangwende CA. Maize production is the dominant subsistence and cash crop. It occupies approximately 70% of the cultivated area. Farmers also grow finger millet, pumpkins, groundnuts, beans, sweet potatoes, cowpea and sunflower. Vegetable gardens are widespread, producing a variety of vegetables for consumption and cash. The selling of mangoes and other fruits are sources of income.

Planting of maize is staggered to ensure that farmers spread out the requirements of labor and to minimize the risk of total failure of the crop. Fields that are ploughed in winter and/or have cattle manure applied to them are usually planted to maize. Early maturing maize varieties are preferred for all plantings, but more so for early planting.

Livestock Production

While crop production is the main form of agricultural activity, livestock are also kept. Cattle are the dominant livestock and about half of the farmers own cattle. They are kept as a financial back up. Cattle ownership influences the cropping pattern in a variety of ways in which they interact with crop production. They provide draft power, so that farmers with draft power can plow large pieces of land and on time. Draft power also assists during weeding and provide transport on the farm. Catthe supply manure for improving soil fertility. In return, crop residues are fed to cattle in the dry season when the quality of feed in the pastures gets low.

Administrative Institutions

Farmers interact with two institutions of leadership, i.e., the traditional and the local government administrative structures. Administratively, the CA is divided into five areas. The five areas are comprised of a total 28 wards. An elected councilor represents each ward in the local government. On average, each ward contains between 800 and 1000 households. The ward cuts across several villages.

There are also members of parliament, elected on a constituency basis. They have a strong influence through ground level interaction with party and district structures. The CA consists of two parliamentary constituencies. The members of parliament and the councilors are elected on political party lines. In the area, the political parties have no strong influence on the farming activities of farmers. However, they make farmers attend meetings regularly. Such meetings take away time from the farmers time as households need to be represented by at least one person during such meeting. This is even more taxing for small households as the absence of one member represents a larger proportion than where more members are available.

Parallel to the official administrative structure is the traditional leadership structure. The lowest group in this structure is the traditional village. The average number of households in a traditional village is 100, varying from 20 to 200. On average, a ward contains 10 villages. Therefore, the total number of households in the whole CA could be estimated at 28,000. The hierarchy of the traditional leadership comprises a chief for the CA. Below him are four headmen. The lowest traditional leaders are village heads, also called *kraal* heads.

The traditional leadership is recognized by the government, to the extent that the chief and the headmen receive government allowances. They are also allowed to rule over customary law cases. Through being custodians of the cultural practices, they have a strong influence on the farming activities of the farmers. For example, they influence the number of days and the specific days of the week on which their subjects should rest from manual work. Ostensibly, this is taken as a sign of respect for the ancestral spirits of the area. The traditional day of resting is Wednesday. In other areas in Mangwende CA, two days have been reserved for resting, i.e., Tuesday and Wednesday. During such rest days farmers can only work in the wetlands area, particularly the gardens and on sweet potatoes. This law has a strong bearing on the allocation of labor that households can achieve.

Traditional leaders determine exploitation of natural resources. Between 1980 and 1996, the government transferred the right to allocate land from the village heads to land committees operating through the local government and this failed. Therefore, the responsibility to allocate land reverted to the traditional leaders.

Traditional leaders also enforce the laws meant to ensure sustainable exploitation of trees, such as allowing only dead trees to be used for firewood. As a result, of the restriction and the shortage of trees in the area, bricks are used for constructing houses. Besides, they allocate land on which tree plantations are established. In most cases, Eucalyptus species are planted.

Religion, Culture and Education

The area is well served with primary schools that provide free education, in line with the government policy. However, various levies have to be paid. Two boarding schools were established before 1980. Many more day schools were established after 1980. The teachers and the pupils in these schools provide a market for some of the farmers' produce, particularly on days when schools meet for sports events.

Farmers in Mangwende CA are predominantly Christians. Nevertheless, they also maintain their traditional beliefs. Both beliefs have a bearing on the time available for farming activities. On the one hand, Christianity entails that farmers take a complete rest on the seventh day of every week, i.e., Sunday. Married women also have mothers' unions, which are associations of women from particular churches. The union members meet once a week, on Thursday, to pray and make arrangements on duties to be taken in the running of the main church. These activities therefore take away some days from the potentially available labor within the households.

Traditional beliefs entail some farmers to believe in witchcraft, to the extent that they believe that their health, productivity of livestock or crop yields are influenced by witchcraft. The belief that yields are a function of witchcraft means that they do not believe that only the resources they use and the level of management determine yields.

Research and Extension Support

Research is conducted by the Department of Research and Specialist Services (DRSS). The Farming Systems Research Unit (FSRU), a unit of DRSS conducts adaptive research in the area. In addition, other research institutes also conduct on-farm research in Mangwende and/or CAs of similar characteristics. However, the traditional system is for technologies to be channeled from research to extension and then extension imparting the new technologies to farmers. The lowest stratum in the extension services is the extension worker. One extension worker services one ward. A single ward has between 800 to1,000 households. With such a low extension worker to farmer ratio, farmers are serviced in groups to make extension workers access more farmers at a time. While this approach may be cost effective, it is not appropriate for delivering technologies that are specific to farmers of different socioeconomic circumstances. Since technologies have to be disseminated to the whole group, they might actually not be appropriate to many farmers. As such, many farmers might be getting less return from attending some of the meetings. Nevertheless, extension allows farmers to meet each other for farming purposes. Therefore, even though the extension messages might not be appropriate for the farm, the farmers have the opportunity to share and learn from each other during and after the meetings.

Input suppliers also interact directly with the farmers. They sell chemical fertilizers and crop protection chemicals directly to the farmers. In so doing, they also propagate use of the products they sell. They also sell through the groups set up by extension. Farmers could be members of social clubs involved in activities as such sewing and money lending. The clubs are promoted by NGOs, and usually target women.

Mangwende CA was chosen for this study to take advantage of the experimental research results of institutions working in the area. In addition, entry into the area was facilitated by the FSRU. The FSRU had already established some research protocols with stakeholders in the area. This was an important consideration at the time survey work was conducted as the country was experiencing political tension. The CA also had characteristics similar to those of other areas where on-farm research had been conducted in Zimbabwe.

Data Collection

Sample Selection

Three wards were randomly selected from the 28 in the CA. Lists of the names of households in each village in the selected wards were compiled from the village lists kept by village heads. A household was defined as a group of people who shared the same kitchen. Thirty-five households were selected randomly from each ward, to give a sample size of 105 households. This number was considered large enough to allow some households to drop out of the survey and to leave the desired sample size of 100.

Enumerator Selection and Training

Enumerators were selected from within the wards in which the survey was conducted. The questionnaire was pre-tested together with the enumerators. The pre-testing exercise additionally served as training for the enumerators. Thorough training was necessary so that the enumerators were clear about the objective of the survey and how to administer the questionnaires and on the relationship of the survey to other activities in the area, particularly political activities.

Types of Surveys and Primary Data Collection

The study utilized both secondary and primary data sources. Policy changes that affect the agricultural activities of smallholder farmers were reviewed from secondary sources of information, particularly, Government of Zimbabwe, World Bank and IMF publications. Primary data were collected through the sample survey. Focus farmer groups were interviewed on general types of data, e.g., labor required for undertaking various farming activities. For example, activities undertaken with ox-drawn implements were differentiated from those conducted with hand held implements. Group interviews were conducted as discussions using guidelines. The discussion guideline is presented in Appendix B. The characteristics of "typical" households in the area were elicited during the group interview.

The second part of the survey was a detailed questionnaire survey. The questionnaire mostly used open-ended questions, with a few pre-coded ones. Data on resource endowments for each household were collected. These resource endowments appear as right hand side constraints in the models. The survey also collected the activities that farmers carried out as part of their livelihood strategies. Data were collected on the following aspects:

- Household composition, in terms of age of members, gender, years of education of each member, their participation in farming activities (fulltime, part time or not working) and whether the members were present in 1995 and 1990.

- Fertilizer purchases and prices paid over time: The quantity and prices that farmers paid for fertilizers in 2001, 2000, 1995 and 1990. Farmers remembered the number of bags of fertilizer they bought over the years, but they found it difficult to remember the prices they paid six and 11 years ago, i.e., in 1995 and 1990. The economy of Zimbabwe had hyperinflation beginning 1998 up to the time of the survey. This might have made farmers concentrate on the short-term changes in input prices, rather than on the longer-term price trends that was sought in the questionnaire.

- A list of other methods of improving soil fertility practiced on the farm and the size of the area on which each method was used.

- Agricultural operations performed on each crop, e.g., land preparation, planting, weeding, fertilizer application and rate of application, weeding, application of cattle manure and other organic sources. The timing of each activity and input application rates was also collected.

- The time taken to do each activity on a unit of land and the gender of the people responsible for doing the activities. The payment, in cash or kind, for work that casual workers carried out.

- The total crop produced from each plot in 2001, and the total production they realized in a normal season (farmers considered 2001 not being typical). The total production was estimated by farmers, using their experience to estimate the number of units harvested. Yields were given in various units of measurement, e.g., bags (90 kg bags and 50 kg bags), ox-carts and buckets. Informal interviews were carried out to determine the quantities in non-standard measures like ox-carts. Farmers were asked to give the number of bags that fit into a their oxcart as the oxcarts were of different sizes.

- Ownership of gardens. If gardens were owned, the crops planted in them, when the crops were planted, and soil fertility management practiced on each crop was collected.

- Size of the land under unmanaged fallow and the reasons for leaving the land under unmanaged fallow, over time.

- Non-crop activities carried out on the farm. Gender of the persons taking part in the activity, the time required for conducting these activities, the expenditure incurred in carrying out the activity, and the income earned. They were also asked for the time of the year when activities were conducted.

- Amount of cash remitted to the household in 2001, 2000 and 1999 and when in the year cash was remitted.

- Total cattle owned and how many of them were draft animals. Methods used for accessing draft power when they were not owned, and if hired, the cost of hiring draft power.

- Quantities of crops sold in 2000, the market on which they sold and the producer prices realized.

- Frequency of contact between household members and extension agents.

- Group(s) or club(s) to which household members belonged and the activities of each group or club .

- The amount of credit that any member of the household obtained in 2000, 1999, 1995 and 1990. The purpose for which the credit was applied and whether it was repaid. For farmers who were denied, credit, the reason(s) for being denied.

- Total size of the farm;

- Knowledge about organic matter based methods of improving soil fertility. The methods they were using and the area under each mathod. An indication of whether they were going to increase the area allocated to the crop.

Appendix B presents the questionnaire. Additional information was obtained through open-ended questions posed to selected farmers during informal interviews. The discussion centered on a better understanding of the responses that farmers had given during the questionnaire interviews.

Secondary Data Sources and Collection

Technical coefficients for new soil fertility management technologies not yet disseminated to farmers for adoption, like improved fallows and green manure, were obtained from published results of experiments conducted in the area by the FSRU and at Domboshawa Training Center by ICRAF-Zimbabwe.

Agroforestry improved fallows. In agroforestry improved fallow technologies, tree species are planted in a crop-fallow rotation. The primary objective is to use the tree species planted in the fallow to fix nitrogen. To utilize the residual soil fertility in the improved fallows, field crops are planted in the fallow after the trees have been removed.

The results from experiments conducted by ICRAF-Zimbabwe research team at Domboshawa Training Centre (17° 22' S, 31° 14' E) in Zimbabwe were used. The training centre lies in the same province as the study site, Mangwende CA. They have similar climatic and soil conditions. The experimental results were reported in

Mafongoya and Dzowela, 1999, Mafongoya and Dzowela, 1998, and Dzowela, 1993 and Dzowela, 1992. Chibudu (1998a) reported on *Sesbania Sesban* improved fallow trials conducted on farm in Mangwende CA. Kwesiga et al. (1992) had similar experiences in Zambia, but the results from Zambia were not used.

One-year, two-year and three-year fallows were tested at Domboshawa Training Centre in Zimbabwe. *Sesbania sesban*, pigeon pea (*Cajanus cajan*) and *Acacia angustissima* were used in the fallows. Improved fallows increased the yields of post-fallow maize. Maize planted on fallow plots either had no fertilizer or had half the recommended fertilizer levels applied (Mafongoya and Dzowela, 1999). Table 3-1 shows the maize yields for two years of cropping after improved fallow at Domboshawa Training Center, Zimbabwe. In all cases, *Sesbania sesban* fallow had the highest maize yield, followed by pigeon pea and lastly *Acacia*. *Acacia* fallow required more labor at all times, especially for cutting the trees, when planting the following maize and when weeding maize. *Acacia* had re-growth during the years when maize was planted. Therefore, it required more labor for weeding maize as the re-growth would have to be cut during weeding. Farmers were likely to find the other species more attractive compared to *Acacia* and it was not included in the model. *Sesbania sesban* had higher yields than pigeon pea, but the two had different labor requirements. For example, pigeon pea, which can be directly seeded, required one person-day per hectare at planting compared to five person-days for *Sesbania sesban* seedlings. Therefore, a diverse group of farmers could potentially adopt a mixture of the technologies. Both *Sesbania sesban* and pigeon pea were included in the model. The responses from the third year maize were depressed and Mafongoya and Dzowela (1999) attributed this to the early nitrogen

release by high quality biomass. The maize in the first two years after the fallow was considered.

Table 3-1. Maize yields for two years of cropping after improved fallow at Domboshawa Training Center, Zimbabwe.

Improved fallow species	Fallow Duration	Maize yields (000 kg ha^{-1})			
		Nil fertilizer		Fertilized maize[a]	
		Year 1	Year 2	Year 1	Year 2
Pigeon pea	1	3.2	2.4	3.7	3.8
	2	3.1	2.4	3.8	3.9
	3	3.5	3.6	3.5	4.7
Sesbania sesban	1	3.8	3.9	4.0	4.1
	2	4.0	5.1	3.9	5.3
	3	3.1	5.6	5.3	6.5

[a] 38 kg N ha^{-1} applied as 12 kg N ha^{-1}, 21 kg P ha^{-1} and 14 kg K ha^{-1} at planting and 26 kg N ha^{-1} as a top dressing.
Source: Dzowela (1993), Dzowela (1992), Mafongoya and Dzowela (1999)

Improved fallows were planted at the end of December, the first quarter of the model. In the smallholder farming system, this would allow farmers to plant some crops before improved fallows. Nevertheless, activities conducted on improved fallows would still compete for labor with cropping activities since farmers would still need to plant late crops and to weed them. *Sesbania sesban* and pigeon pea could be seeded directly into the soil. However, for better establishment, *Sesbania sesban* would have to be planted from seedlings, which is recommended. Chikura (1998) reported that farmers in Mangwende and another area used different methods of establishing *Sesbania sesban* nurseries. Access to gardens was not a precondition for the establishment of *Sesbania*

sesban nurseries since farmers used a variety of locations on the farm, including protected gardens near water sources, for establishing nurseries (Chikura, 1998). *Sesbania sesban* seeds are planted in nurseries for at least ten weeks before the seedlings are transplanted.

At the end of the fallow period, trees from improved fallows have to be cut down and be pruned to allow them to be incorporated by ox-drawn plows. This takes considerable time. Time required for these operations was recorded on station but was reduced by half in this study since farmers would not be meticulous in their pruning of leaves as researchers are inclined to be.

Cowpea green manure. The potential of legumes as green manures has been a subject of considerable research in Zimbabwe and elsewhere (Hikwa and Waddington, 1998; Mapfumo at al, 1998; Muza et al., 1998; Gladwin et al., 1997). Chibudu (1998b), reported on work conducted with cowpea in Mangwende CA and the results are used in this study. Chibudu (1998) reported maize yields in the first year after the green manure. Maize yields were 5300 kg ha^{-1} with no fertilizer applied. These yields were reduced by 40% in the model.

Maize yields reported on station were likely to be much higher than what farmers would realize (CIMMYT, 1988). Therefore, yields realized on improved fallow and green manure experimental plots were reduced to bring them to yields that farmers are likely to realize in their own fields.

The Household LP Model

A five-year LP model was constructed using the Premium Solver Plus V3.5 for Excel to reflect the livelihood system of the smallholder farmers. The model was run for each household in the sample (n = 99) using household specific parameters from the

questionnaire survey and technical coefficients from group interviews. The objective function in the models was to maximize discretionary income from farm and non-farming activities, subject to various constraints, reflecting household characteristics, such as households composition, draft power ownership, available arable land. The model was set at the household level.

Validation of the model was necessary to ensure that the model reflected the farmers' livelihood strategies before new technologies could be brought into the model. Validation was done in two stages. The first stage, conducted in the research area, involved taking the computer model to farmers. Initially only computer printouts of the model were discussed with the farmers. However, the printouts restricted the discussion that could be carried out with the farmers about their livelihood system. Farmers wanted to find out what effect some of the changes in the manner in which they were conducting their activities would have on the household. Therefore, the laptop computer was taken the research site. Validation was done using a sub-sample of the farmers in the research area. The structure of the model, i.e., the activities and the constraints identified in the system, were pointed out to the farmers. The model would then be run for each household and the results would be discussed with the farmer. The model was also validated in terms of how it was sensitive to shocks in the systems. In this regard, fertilizer prices were varied to see the model's prediction of how households were likely to respond. The responses that the model predicted were further discussed with the farmers.

Alterations on the model that farmers suggested were incorporated, as far as possible, while still in the research site so the implications of the changes could be discussed with

farmers. Farmers were agreeable that the model simulated their livelihoods well, especially in its ability to identify resources that were limiting them in farming operations.

The second level of validation compared the level of activities reported by the farmers to the data generated in the model. This second validation was done after the model had been run for all households. Two variables were considered critical for the second validation, i.e., the area planted to maize and the area under unmanaged fallow. Maize was important for validation because it was the major staple and cash crop for the farmers. In addition, maize was the crop for which the potential for adoption of improved fallow technologies were to be evaluated in this study. The new technologies compete for land with crops or replaces the land under unmanaged fallow. It was necessary that the unmanaged fallow in the model was as close as possible to what farmers were practicing. Therefore, the unmanaged fallow area was used as another criteria for validation.

Following validation, new low cash cost, labor-demanding technologies were then included into the LP models. Solutions to the new LP models showed whether the new technologies had a potential to be adopted, *ceteris paribus*. Results were summarized based on households types, particularly draft power ownership, number of household members working fulltime of the farm, and farm size. The criteria were meant to capture diversity observed between households.

The effect of the new technologies on area under maize, area under improved fallows, cash for discretionary spending, land use, and proportion of the land planted with

improved fallows were assessed from the solutions of the model, before and after including the new technologies in the model.

Data Analysis

Survey data were coded and entered into Microsoft Office Excel spreadsheets. Descriptive statistics were obtained using Microsoft Office Excel. Regressions were conducted in SPSSPC and LIMDEP.

T-tests for comparison of means were conducted to determine differences before and after the new technologies and policies. Ordinary least squares regression models were also run to determine the effect of the household attributes on the pattern of behavior emerging from the models. To evaluate the effect of different policies that affect prices, sensitivity analysis was conducted by increasing fertilizer prices. Given the rate of inflation in Zimbabwe, looking at a reduction in fertilizer prices was not considered appropriate in this case.

CHAPTER 4
LIVELIHOOD SYSTEM OF THE SMALLHOLDER FARM HOUSEHOLDS

This chapter uses data collected using both formal and informal survey methods from a sample of households in Mangwende Communal Area (CA). The data were used for characterizing the livelihood system of the households. A household was defined as a group of people who worked together and shared food prepared in the same kitchen. Three wards were randomly selected and 35 households were randomly selected from each ward. Out of these, 99 households were successfully interviewed. Aspects of the livelihoods dealt with in this chapter include composition of households, level of resources, farming activities, non-crop activities and the farmers' use and experiences with traditional and other methods of improving soil fertility.

The chapter seeks to show the existence of diversity across households and some of the relationships between the characteristics of the households and the activities they conduct to achieve their livelihood objectives. It has already been reported that smallholder farmers have limited resources and multiple objectives (Netting, 1993; Hildebrand, 1986; Ellis, 1992). Nevertheless, while there are these limitations on resources, it should not be assumed that the group is homogeneous. Recognizing the existence of diversity within this sector is critical for technology development for the sector. Diversity arises from differences in resource levels across households and the composition of the household. Households will be in different positions to exploit opportunities that different technological innovations might offer.

Household Composition

Households in Mangwende CA produce their own food for subsistence requirements and some surplus for selling on the market. The composition of households plays a pivotal role in determining their behavior. Household composition, in terms of the number of household members and their ages, determines the quantity of food required for subsistence consumption and the labor available from household members for undertaking production activities. In a household of six people, consisting a husband and wife working fulltime on the farm, plus four children below twelve and unable to participate in farming activities, the husband and wife have to bear the burden. Another household, also composed of six members who are all mature enough to work on the farm, is better placed to produce subsistence requirements and surplus for sale. These examples are silent on the gender composition of the second family. If some activities are specifically conducted by males or females, the second household can be constrained if its gender composition was skewed.

In the sample, the average household size was between five to six members, ranging from one to ten. The average composition of the households is given in Table 4-1. Females constitute a larger part of the working adults than males. This is expected since 30% of the households are *de jure* female-headed households (FHHs). Another 20 % are *de facto* female-headed households (FHHs) and 50% are male-headed households (MHHs). Males have a greater possibility of being employed in urban areas as unskilled labor so that males are more likely to move out of the rural area than females.

Sixty four percent of the households have some children that are not yet participating in farming activities. Thirty two percent of the households had at least a child who was

three years or younger. Babies take considerable effort to look after and reduce the labor available from the mother or another older female for undertaking farming activities.

Table 4-1. Composition of sample households (n = 99).

Characteristic	Mean	Maximum
Household Size	5.6 (0.2)[a]	10
Adult working males	0.9 (0.1)	5
Adult working females	1.4 (0.1)	5
Children: Working	1.8 (1.1)	7
Not working	1.5 (1.2)	5

[a]In parentheses are Standard Deviations

Gender Composition

Three types of headship were observed in the sample households. These are:

i. Male-headed, where the male head is resident on the farm;

ii. *De facto* female-headed, where the male head is not residing on the farm, and a female, usually the wife of the head of household, is responsible for making most of the farming decisions of a daily basis;

iii. *De jure* female-headed, where the female head of household is single.

The distribution of the households by headship shows that females (*de jure* or *de facto*) constituted a significant part of the decision makers in smallholder farms. Polygamy is not common. Fifty percent of the sample households are headed by resident males and the other 50% are female-headed. The male heads in *de facto* FHHs visit the rural households during weekends and public holidays. More visits were made during the rainy season so they could assist with labor in the farming activities.

The average age of the heads of household is 57 years. The three types of head of household have significantly different ages (p = 0.03). Average ages of heads of MHHs,

de facto FHHs and *de jure* FHHs are 58, 50 and 60 years, respectively. The ages of heads in MHHs and *de facto* FHHs are significantly different ($p = 0.004$). The ages of *de facto* and *de jure* FHHs are significantly different ($p = 0.001$). Ages of head of MHHs are not significantly different from that in *de jure* FHHs ($p = 0.1$).

Male heads of households staying away from the households are the youngest of the three headship types. Younger males have a higher probability of being employed and many are in the process of looking for work in urban areas. Therefore, the heads of young households are most likely to be staying away from the farm. Males are expected to attempt to get into fulltime formal employment, regardless of their level of skills. It is often only after they fail to secure a job in the urban areas that they might settle in the rural areas permanently and eke a living from farming. If fortunate to be employed, earnings are invested in the rural areas, i.e., buying farming implements, cattle and building a decent homestead.

The young households where the male stays away from the household have young children of school age, but only a few hands to carry out farming activities. *De facto* female heads in such families have to take care of the family requirements, while also producing food for the household. Therefore, such households are likely to have a higher dependency ratio and labor is likely to be a constraint during farming.

De jure female heads of household are the oldest of the three groups. Females become *de jure* heads of household for a number of reasons, including the death of the husband due to old age or divorce. The survey did not elicit reasons for the females being single. A summary of the resources that households headed by different gender possess are presented in Table 4-2 and discussed in the sections below.

Table 4-2. Resources possessed by households headed by different gender.

Resource	Household type			Significance level
	MHH (n = 49)	*De jure* FHH (n = 21)	*De facto* FHH (n = 30)	
Percent owners of draft power	66	65	55	0.6200[a]
Proportion of labor from males	0.51 (0.21)[c]	0.38 (0.27)	0.30 (0.20)	0.0009[b]
Number of bags of fertilizers bought in 2001	5.85 (5.91)	7.85 (5.93)	5.36 (4.62)	0.2800[a]
Size of the farm (ha)	2.64 (1.10)	2.47 (1.03)	2.52 (1.09)	0.8200[a]
Cash income remitted (Z$)	380 (1,240)	2,700 (5,790)	640 (1,700)	0.0098[a]
Number of household members working fulltime on the farm	2.55 (1.04)	1.95 (0.94)	2.21 (1.18)	0.0800[a]
Percentage of household differentiating labor by gender	55	55	48	0.8000[b]
Age of head of household	58 (12.6)	50 (9.6)	60 (13.4)	0.0300[a]

[a]Chi-square for goodness of fit
[b]F-test for differences across groups
[c]In brackets are Standard Deviations.

Labor

Smallholder households typically use family labor, only hiring casual labor when the household labor is limiting. Each member of the household, old enough to participate in farming operations, contributes labor. Members often undertake different tasks on the farm to maximize the contribution of each member to the well being of the household. Males do most operations that use ox-drawn implements. When male labor is insufficient, females participate in the operations, or male labor has to be hired. An F-test

for difference in the number of members working fulltime on the farm across MHHs, *de facto* FHHs and *de jure* FHHs, is not significant (p = 0.088). *De facto* FHH have 1.95 members working fulltime on the farm. This is only slightly less than the number of members working fulltime on the farm for the other types of households. MHHs and *de jure* FHHs have 2.55 and 2.21 members working fulltime on the farm, respectively.

Parameters for labor input into different operations were obtained from focus groups. They are presented in Appendix C. Labor requirements for land preparation depended on whether or not a household used draft power. Households without draft power hire it at a cost. Further, households without draft power use hand hoes for weeding while those with draft power use ox-drawn cultivators in combination with hand hoes. This has implications for labor use, particularly female labor. Use of hand hoe weeding alone requires more labor than a combination of ox-drawn cultivators and hand hoes. Since female labor is usually used for hand weeding when labor is differentiated, more female labor is required when there is no draft power.

In households that differentiate tasks by gender, the shortage of labor for undertaking specific tasks may limit the ability to conduct certain activities. In 52% of the sample, male and female labor is differentiated during farming operations. However, even when labor is differentiated, operations that use ox-drawn implements are still undertaken by males, unless there are no males in these households.

Labor is least differentiated by gender for conducting maize operations (Table 4-3). Technologies for reducing the labor required for carrying out operations in maize production are available. Furrows made with ox-drawn plows are used for planting. Ox-drawn cultivators are used for weeding between the rows while hand-hoe weeding are

then be used within the row. The ox-drawn cultivator reduces the time for weeding by 30%.

Table 4-3. Differentiation of labor in selected activities (n = 99).

Gender	Land preparation (%)	Maize Planting (%)	Groundnuts	
			Planting (%)	Weed (%)
Males	65.6	3.3	2.2	2.2
Females	1.3	22.8	60.0	51.6
Both	33.3	73.9	37.8	46.2

For 74% of the households, maize is planted by both males and females. In some households, males plough the land while females drop seeds into the furrows all at the same time. This explains the 22.8% of the households that only use female labor for planting maize. In reality, all family members take part in maize production activities.

Differentiation of labor is most prevalent in groundnut production. Groundnuts are planted using hand hoes, which is labor intensive. Table 4-4 shows the general use of labor of different gender by households that differentiate labor by gender.

Females undertake most of the planting and weeding in groundnuts. Males participate during weeding in 48.4% of the households. Farmers argued that males lack the "precision" required for planting groundnut. It is generally believed that males cannot weed groundnuts as well as females. In fact, some held the myth that if males walk in a groundnut field, the field has a low yield, as many plants have underdeveloped seeds. Operations for manure production activity are undertaken by males.

Table 4-4. Differentiation of operations by gender.

Crop and Operation		Male	Female
Plowing		X	X
Planting Maize:	Hand hoes	X	X
	In plow furrow		X
Weeding Maize:	Hands		X
	Ox-drawn cultivator	X	
	Ox-drawn plow	X	
Groundnuts/Bambara nuts:			
	Hand hoes planting		X
	Hand hoe weeding	X	X
Planting Finger millet:	Dribbling behind plow		X
	Hand hoe weeding		X
Planting Cotton:	In plow furrow		X
Weeding Cotton:	Using cultivator	X	
	Hand hoes	X	X
Harvesting/Picking Cotton		X	X
Planting Sunflower:	Dribbling in plow furrow		X
Weeding Sunflower:	Using cultivator	X	
	Hand hoes		X
Cattle manure application		X	

Farm Sizes

The size of the arable land has continued to fall as the population has increased. Over time, households have also encroached marginal lands originally designated for grazing areas. This is a common trend in the communal areas of Zimbabwe. Arable land

available to the household is likely to be a major determinant of their agricultural production patterns. Table 4-5 presents the distribution of arable land available to households. Farms are small and do not exceed 5 ha. Mean size of arable land is 2.6 ha. The distribution shows that 76% of the households have less than 3.5 ha of arable land. The farm sizes are not significantly different ($p = 0.8$) across MHHs, *de facto* FHHs and *de jure* FHHs. FHHs possess 2.6 ha and both *de facto* and *de jure* FHHs possess 2.5 ha. However, differences in farm sizes between owners and non-owners of draft power are significant ($p = 0.037$). Owners and non-owners of draft power, own 2.7 ha and 2.3 ha, respectively.

Seventy nine percent of the households owned gardens, i.e., plots in wetlands. Sixty percent of the households planted maize in their gardens. Garden maize is planted between September and October. Garden maize still in the field after consumption of green maize is harvested between January and February when grain stocks are depleted for food-deficit households. This makes gardens important to the households for food security considerations.

In the communal farming areas of Zimbabwe, land is considered as common property. The community rights are represented by the local leaders (chiefs or headmen). Every household in the community is entitled to a home field where the homestead is located and other fields usually located about two kilometers from the homestead. When land suitable for setting up gardens is available, a household can also be allocated a garden plot. Households have heritable rights to the arable land allocated to them. The size of the farm that households own is historically determined. Some households inherited larger farms even though they are young. Others have smaller farms because they are

recent immigrants into the area. Households that settled in the sixties or before have larger farms. Such households also accumulated cattle and draft power. This can explain why the size of the farm is not significantly different across households headed by different gender. During group interviews, farmers indicated that resources are obtained in many ways such that it was possible for MHHs, widely expected to have better resources and higher levels of production than their female counterparts, to perform worse than FHHs.

Table 4-5. Distribution of size of arable land and gardens.

Size category (ha)	Percentage of households	
	Fields	Gardens
0	0	21
> 0 – 0.5	0	57
> 0.5 – 1.5	18	21
> 1.5 – 2.5	36	0
> 2.5 – 3.5	32	0
> 3.5	24	0
Average	2.6 ha	

Households cannot sell land, even if they wanted to leave the area. Land cannot be used as collateral when applying for loans, as households hold no title to it. Grazing lands are communally owned, so that any household can graze livestock on unallocated land. Animals also graze on crop fields after crops have been harvested.

Since households cannot sell land, no legitimate land market exists. Arable land that cannot be utilized is kept as unmanaged fallow and is open for grazing. Households

borrow more land when they require it. Cases where some households sold their pieces of land were reported. Land is sold under the disguise of selling the improvements done on the land, e.g., the dwellings, water-wells and fencing around the land. Land sold this way is usually bought by locals, since there is a general resistance to the introduction of "foreigners" into a village.

Even though the size of the arable land is small, farmers are unable to cultivate all the land. The percentage of households putting some land under unmanaged fallow has increased over the years: 40%, 53%, 76% and 83% of households had land under unmanaged fallow in 1990, 1995, 2000 and 2001, respectively. The size of the land under unmanaged fallow has also increased. in 1990, owners and non-owners of draft power left 0.3 ha and 0.7 ha under unmanaged fallow, respectively. The unmanaged fallows increased to 0.9 ha and 1.1 ha in 2001, for the two groups respectively (Table 4-6). The major reason given for leaving the land as unmanaged fallow was the shortage of chemical fertilizer and lack of cattle manure.

In 1990 and 1995, the area under unmanaged fallow was weakly correlated to the size of the farm. The correlation coefficients between size of the farm size and area under unmanaged fallow in 2000 and 2001 are 0.59 and 0.44, respectively. This suggests that in 2000 and 2001, households were only able to cultivate a fixed area, regardless of the size of the farm, so that the remainder of the farm under unmanaged fallow was correlated to the size of the farm. In 1995 and 1990, households cultivated according to the size of the arable land they owned, those with large farms also cultivated larger pieces of land, and the area left under unmanaged fallow was not correlated to the size of the farm. Comparing the scenario between 1990 and 1995 to that in 2000 and 2001, suggests

that when farmers have access to resources for improving the fertility of their soils, they could cultivate more land than they did in 2001 and 2000.

Table 4-6. Area under unmanaged fallow by ownership of draft power over time.

Year	Area under unmanaged fallow		Significance level of differences
	Owners of draft	Non-owners of draft	
2001	0.87 (0.59)[a]	1.06 (1.00)	0.27
2000	0.78 (0.71)	1.08 (1.06)	0.10
1995	0.50 (0.68)	0.79 (0.88)	0.08
1990	0.33 (0.59)	0.67 (0.90)	0.03

[a] In parentheses are Standard Deviations

Ownership of Cattle and Draft Power

Cattle are one of the most important assets on the farm. During a wealth ranking exercise conducted by farmers in Mangwende CA, households with cattle were characterized as being in the wealthy group that realized higher crop yields (Farming Systems Research Unit, 1993). Cattle supply draft power and manure and are used as a living asset, capable of being liquidated when cash is needed. They are only sold in time of stress and emergency.

Draft power is critical to the timing of farming activities on the farm. To achieve good seed germination and high yields, crops have to be planted at the right time after sufficient rainfall has been received early in the season. Households without draft power have to wait until draft power owners have completed their own operations before they can hire, and might not be able to plant when the soil has the ideal moisture. However, because of the strong social networks in the systems, draft owners and non-owners

arrange to ensure that those who do not own any draft power have some land prepared for them to have some early planting. Three quarters of the households owned at least one head of cattle. Ownership patterns across different household types are shown in Table 4-7.

Table 4-7. Distribution of cattle ownership between households.

Number of cattle	% of whole sample (n = 99)	% of *de jure* FHH (n = 29)	% of *de facto* FHH (n = 21)	% of MHH (n = 49)
0	25.3	31.0	14.3	26.5
1-3	26.3	24.1	28.6	26.5
4-5	14.2	13.6	17.1	12.3
6-5	18.2	13.7	28.6	16.4
More than 8	16.0	16.2	9.6	18.2

Fifty five percent of the sample had adequate draft animals to make a span (Table 4-8). A span comprises of two oxen. Survey results show that households with more than five cattle have at least two draft animals required for making a span. Households that have one draft animal had to team up with others to make up a span. Draft power ownership is not significant different ($p = 0.6$) across MHHs, *de facto* FHHs and *de jure* FHHs. However, 55% of *de jure* FHHs have draft power, this is the least percentage compared to 66% and 65% for MHHs and *de facto* FHHs, respectively. This suggests that *de jure* FHHs are disadvantaged in terms of draft power, compared to MHHs and *de facto* FHHs.

Table 4-8. Distribution of draft power ownership.

Number of draft power animals	% of households
0	37.4
1	7.1
2	24.2
3	11.1
4	17.2
> 5	3.0

Table 4-9. Methods of accessing draft power by household type.

Means of accessing draft power	Type of Household[a]		
	% of MHHs (n = 26)	% of *de facto* FHHs (n = 12)	% of *de jure* FHHs (n = 20)
Hire at a charge	46	66	65
Borrow from neighbors	39	17	20
Share with neighbors	15	17	15

[a] For households that do not own draft power or need to supplement their own draft power.

Crop Production Activities

Crop production is based on summer crops planted between October and January. The major crops produced during the wet season are maize, groundnuts, Bambara nuts, finger millet, and sunflower. Vegetable production and market gardening are practiced when gardens are available. Various vegetables are produced in the gardens for consumption and for sale. Mangoes and other fruits are sold for supplementary income.

As the preferred crop, maize receives the highest level of management. Fields that are ploughed in winter to conserve moisture and/or have cattle manure applied to them are

planted with maize. The little chemical fertilizer that households have is usually devoted to the maize crop.

Maize occupies 53% of the area under crops. Previous reports have noted that maize occupied 70% of the arable land under crops, suggesting that the area under maize is declining. Farmers indicated that the decline in the area under maize is mainly due to the high cost of chemical fertilizers. Groundnuts are the second major crop planted to 20% of the area. The size of the land allocated to crops and the percentage of households growing the crops are presented in Tables 4-10 and 4-11, respectively. All households grow maize and 87% of the households plant groundnuts. Only 7% and 9% of the households plant cotton and soybeans, respectively. Soybeans were introduced to the area in the mid-eighties through on-farm activities of the Department of Research and Specialist Services and by the University of Zimbabwe since 1996. As such, households are growing the crop on a trial basis.

Households establish at least two plantings of maize, with an average spacing of two weeks. Survey results show that 63% of the sample households have two plantings, 19% have one, 16% have three and 1% has four plantings of maize in separate plots. Maize plantings are staggered to avoid the adverse effects of the mid-season drought that usually occurs in January and to reduce the labor and cash inputs to be purchased at any given time. Staggering also prolongs the period over which households harvest green maize for consumption. Farmers plant maize over the period from end of October to early January. Seven percent of the maize plots are planted during late October. Thirty percent of the plantings occur over the first two weeks of November, 26% are planted during late November, 22% in early December, 13% in late December and 2% in early

January. Planting of groundnuts is also staggered. Twenty seven percent of the households had two plantings and 3% had three plantings.

Table 4-10. Average area planted to crops by ownership of draft power.

Crop	Whole sample (ha)	Draft Power owners (ha)	Non-owners of draft power (ha)
Maize	0.95 (0.50)[a]	1.04 (0.59)	0.72 (0.32)
Groundnuts	0.35 (0.28)	0.37 (0.76)	0.30 (0.32)
Bambara nuts	0.12 (0.11)	0.12 (0.10)	0.12 (0.12)
Sweet potatoes	0.13 (0.19)	0.13 (0.19)	0.13 (0.18)
Finger millet	0.07 (0.13)	0.07 (0.88)	0.05 (0.11)
Sunflower	0.04 (0.11)	0.05 (0.13)	0.02 (0.07)
Cotton	0.07 (0.25)	0.09 (0.30)	0.04 (0.16)
Soybeans	0.02 (0.13)	0.03 (0.10)	0.02 (0.13)

[a]In parentheses are Standard Deviations

Soil Fertility Management

Soils in the area are poor in fertility and require external inputs. Without these inputs, close to nothing is harvested due to low yields. This explains why households indicated that they had unmanaged fallow because of shortage of chemical fertilizers. Farmers are aware that it is not worthwhile plant maize unless some form of soil fertilizer amendment is to be applied. Households use fertilizers and manure for improving soil fertility. For chemical fertilizer, households mainly use Compound D fertilizer (8% N, 14% P_2O_5, 7% K) as a starter fertilizer and Ammonium Nitrate (34.5% N) as a top dressing fertilizer on maize.

Table 4-11. Percentage of households growing different crops by ownership draft power.

Crop	Whole sample	Draft Power owners	Non-owners of draft power
Maize	100	100	100
Groundnut	93	91	92
Bambara nut	81	85	76
Sweet potato	57	55	59
Finger millet	28	28	27
Sunflower	13	17	8
Cotton	9	10	8
Soybean	7	10	3

Ninety three percent of the households used some fertilizer in the 2001 season. The escalation in the prices of fertilizers (compared to that of agricultural commodities) was the major reason for households reducing the quantities they purchased (Table 4-12). However, Figure 1-2 shows that farmers did not necessarily face declining returns from production of maize. The ratio of fertilizer prices to maize producer prices reveals that the price of maize increases at a faster rate than that of fertilizers. Farmers gave the increase in fertilizers prices as the reason for purchasing less fertilizer, suggesting that they are concerned with the nominal fertilizer price. This is expected since maize is also the subsistence food crop produced on the farm.

In addition, households reduced the quantities of fertilizers due to the death or retrenchment of members of the household (fathers or children) who used to remit money, indicating the importance of cash remittances on fertility management. Retrenchment of workers increased after 1991 when the structural adjustment program was initiated.

Table 4-12. Change in average fertilizer use over time.

Season	Average (kg)	Compound D (kg)	Ammonium Nitrate (kg)
1990	595	325	295
1995	515	256	255
2000	315	150	156
2001	310	145	150

Compound D = 8% N, 14% P, 7% K, Ammonium Nitrate = 34.5% N.

The total fertilizer purchased in 2001 represented a 48% decrease from the quantities purchased in 1990. Compound D purchases fell by 55% and Ammonium Nitrate fell by 49% over the same period. Ninety one percent of the households purchased some fertilizer in 2001, indicating that farmers are aware of the benefits from its use and all are striving to get some. However, the decline in its use suggests that alternative sources of improving soil fertility are required to fill the gap left by declining fertilizer use.

Households that do not own cattle are also generally poorer. They can hardly afford to purchase inorganic fertilizers, particularly with escalating fertilizer prices. Consequently, their crop yields are likely to be lower than those for cattle owners.

Use of Chemical Fertilizers

Extension recommendation rates for chemical fertilizers on maize was between 350 and 375 kg/ha Compound D applied at planting and between 250 and 300 kg of Ammonium Nitrate applied as a top dressing, six weeks after crop emergence. Table 4-13 shows the application rates that sample households used in 2001. The rates applied are 38% and 58% of the recommended initial and top-dressing fertilizer, respectively.

Table 4-13. Fertilizer application rates in 2001.

Manure Status	% of maize area	Comp D[a] (kg)	AN[b] (kg)
With Manure	25	119.1	128.4
No Manure	75	131.5	143.8
Average	n.a.[c]	126.0	138.8

[a]Comp D = Compound D (8N, 14P, 7K)
[b]AN = Ammonium Nitrate (34.5% N)
[c]n.a. = not applicable

Use of Cattle Manure

Households that own cattle also have the advantage of owning the manure that accumulated in their cattle pen. Cattle manure is used as a complement to chemical fertilizers. Eighty six percent of the households reported that they dig manure from the cattle pen and store it in a heap between June and August (Nzuma et al., 1998). Manure heaps are allowed to mature for three months, at the end of the period they are transported to the fields and spread. They are plowed into the soil at the onset of the rains. This method of storage produced manure of poor quality and 67% of the cattle owners end up with manure with 0.5-0.9% N, 30% end up with manure with 1.0-1.2% N, which is marginal (Nzuma et al., 1998). Only 3% end up with manure with adequate N of above 2.25% N content (Nzuma et al., 1998).

Three requirements have to be met for households to use cattle manure. They require cattle to produce manure, draft power to transport manure to the fields, and males to provide labor for digging, transporting and broadcasting manure in the field. Lack of these requirements means that cattle manure cannot be used.

The quantity and quality of manure that a household has at the beginning of the season depends on the number of cattle owned and the management in the cattle pen.

Households add crop residues to provide bedding for their cattle during the rainy season and as supplementary feeding during the dry season, when fodder is in short supply. The crop residues influence the quantity and quality of manure. Residues from leguminous crops such as groundnuts add more nutrients and decompose faster than residues from cereals such as maize. Since farmers apply various quantities of the residues to their cattle pens, in different combinations of legume and non-legume residues. Therefore, the qualities of manure they realize vary widely. Households that are using manure indicated that, on average, they only apply manure to a hectare each year.

Household Food Security

It was noted in Table 4-10 that owners of draft power have an advantage over non-owners of draft power as they plant 60% more maize and have access to cattle manure. Households producing more maize, the major staple food and cash crop, are more likely to be food secure. Therefore, households that own draft power are less likely to face a shortage of food compared to those without. A significant relationship ($p < 0.01$) existed between the shortage of food in the household within the last five years and the hiring of draft power. Over the five-year period 1996 to 2000, 25% of owners of draft power experienced food shortages versus 58% of non-owners of draft power. There was no significant relationship between gender of head of household and the shortage of food in the last five years.

Household Expenditures

Cash for buying chemical fertilizers is a limiting constraint for the households, as there are other demands that require cash at the time of buying fertilizers. Seventy two percent need funds for school fees, 57 % need food, while 42% need farming inputs. School fees are paid at the beginning of each of three school terms in a year, i.e., at the

beginning of January, May and September. Households with school going children need school fees in addition to cash for other household requirements. Food items are bought throughout the year and clothing items are bought just before the Christmas festive season. In addition to food, over the period October to December, households need cash for farming inputs and clothing.

Cash Income Remittances

Returns to agricultural labor in the semiarid areas are low compared to returns to wage employment. As a result, many people seek off-farm employment (Hedden-Dunkhorst, 1993). Households with members with regular off-farm income are assured of remittances. Rural people go to the urban area to find manual work in which male labor has a higher potential of being employed. In this respect, women are disadvantaged but contribute significantly to the welfare of the household.

Women remain in the rural area to raise the family, maintaining a presence on the rural home, producing consumption goods and even some surplus for sale. Therefore, the household optimally uses its labor resources while at the same time securing land-use rights, through the continued presence of some household members on the land (Low, 1986). However, the contribution that women make through maintaining a physical presence of the household in the rural areas is difficult to account for and is rarely recognized formally.

Rural households and members who leave the rural areas to work in urban areas maintain linkages with each other. The employed members remit income in cash or kind to the rural households. There is no significant relationship between amount of remittances and age of head of household or gender of head of household. Older households can receive remittances from children working in urban areas, while younger

households, that are predominantly *de facto* FHHs, receive remittances from the male heads who work in formal employment. Chi-square tests showed a significant difference ($p \leq 0.03$) in the distribution of households that had cash remitted to them. *De facto* FHHs had the highest proportion of households receiving remittances, i.e., 63%. *De jure* FHHs are the second with 53% while MHHs have the least with only 32% getting cash remitted to them. However, the age of the head of head of household does not seem to determine probability of households receiving remittances.

Forty four percent of the households received remittances in 2000 and these households received an average of Z$4,000[2]. Across the whole sample, average cash remittances are only Z$1,800. The timing of receipt of the remittances can be critical to farming activities. Of the households that receive remittances, 31% receive cash remittances between October and December, 27% between January and March, 21% between April and June and 22% between July and September. More households receive remittances during the period between October and March since farming inputs and goodies for the Christmas festive seasons are required during that time. Since remittances can be used for purchasing chemical fertilizers, households that receive remittances might have less incentive to adopt improved fallows. *De facto* FHHs receive significantly more remittances ($p = 0.01$) from the male head and other relatives working in urban areas. Considering cash remitted in the second quarter, *de facto* FHHs receive Z$2,750 compared to Z$640 and Z$380 that *de jure* FHHs and MHHs receive. With more remittances, *de facto* FHHs can buy more fertilizers. Therefore, they are expected

[2] Exchange Rate: Z$55 = US$1

to establish less improved fallows and their income to benefits less from adoption of improved fallows.

Non-crop Activities on the Farm

Maize, the dominant cash crop, is marketed between July and September. Households solely relying on it for income have to save cash for all cash requirements during the rest of the year, which is difficult. Non-cropping activities increase the cash income and make it flow more regularly, allowing households to purchase food requirements and ensuring food security.

Non-cropping sources of income include remittances, house construction, vending, herding cattle, poultry production, making peanut butter, making bricks, brewing beer and market gardening (Table 4-14). Some activities are gender specific, e.g., house construction and herding cattle are male activities, whereas vending, making peanut butter and brewing beer are female activities. Poultry production, making bricks and market gardening are gender neutral. The gender specificity of different households means that some households are constrained in some gender during the year.

Some non-cropping activities can only be conducted during certain times of the year (Table 4-14). Households have to select a portfolio of activities commensurate with their objectives and resources to get the most return to their resources at a given time.

Non-crop activities require different labor and cash inputs and differ in their levels of benefits (Table 4-15). Beer brewing is limited to four brews per year. There are two processes of making beer. One takes seven days and the other takes one day. The former is the traditional method but was less preferred as it required more resources, i.e., firewood, water and labor. In the more commonly used method, fermentation is accelerated by use of industrial yeast and sugar.

Table 4-14. Gender differentiation and timing of non-crop activities (n =99).

Activity	% of Households doing activity	Gender[a]	Oct-Dec	Jan-Mar	Apr-Jun	Jul-Sept
Construction	n.a[b]	M	X	X	X	X
Vending	42	F	X	X	X	X
Hire out labor	25	M/F	X	X	X	0
Peanut butter	n.a.	F	0	0	X	X
Poultry	8	M/F	X	X	X	X
Making bricks	6	M/F	0	0	X	X
Beer brewing	11	F	0	X	X	X

[a]M = Males, F = Females, X = Activity undertaken at this time, 0 = Activity not undertaken at this time.
[b]n.a. = not available

House construction involves repairing and making new thatched roofs. Vending, done by females, involves purchasing goods for reselling. Women make peanut butter using a traditional labor-intensive process. The groundnuts used for making peanut butter are taken from own stores or purchased locally. The butter is sold by relatives living in urban areas. Brick making is a labor-intensive activity for unskilled members of poor households to earn an income. Brick-makers incur expenses on firewood and on hire of ox-carts for transporting water.

Extension Service

The government delivers agricultural extension services through extension agents located in each ward. Extension agents used the group training approach to contact farmers. However, evidence from the sample farmers shows that membership to the group alone does not guarantee frequent contact with extension agents. Forty three percent of the households have a member who participates in groups involved in

agricultural extension, yet 26% of those households have no contact with the extension agents and are not satisfied with the level of activity of extension agents. They indicated that they prefer to meet extension once every three weeks. This lack of contact between some groups and extension agents means that agricultural extension groups are no longer very relevant as a vehicle for disseminating agricultural information to the farmers.

Table 4-15. Expenditure and gross revenue for non-crop activities requiring one unit of labor.

Activity	% doing activity[a]	Expenditure (Z$)[b]	Gross Revenue (Z$)
House Construction	16.2	50	250
Vending	42.4	33	100
Hire out labor	24.2	0	45
Peanut butter	n.a.[c]	75	250
Poultry production	7.1	250	420
Making bricks	6.1	50	160
Beer brewing	11.1	33	130

[a] Do not have to add to 100
[b] Z$ = Zimbabwe dollar
[c] n.a. = Not available
Official exchange rate Z$55 = US$1

Only 39% of the sample households have contact with extension agents. The frequency of contact is given in Table 4-16. Forty four percent of the households that have contact with extension agents belong to extension groups. The rest of the households that are in contact with extension agents do not belong to groups. All this suggests that the group approach was not working well. Membership to agricultural extension groups cannot be used reliably as an indicator of level of extension advice

received. Rather, frequency of contact is more appropriate as a proxy for amount of information received.

Table 4-16. Frequencies of contact between extension agents and farmers (n = 39)

Interval in Weeks	% of households with contact
Every week	15.4
Every 2 weeks	7.7
Every 4 weeks	35.9
Every 6 weeks	2.6
Every 8 weeks	15.4
After more that 12 weeks	23.2

Sixty nine percent of the households that have contact with extension are satisfied with the frequency of contact. Nevertheless, some households reported meeting extension only once a year. The implication is that the agricultural productivity of households is likely to be related to the frequency of contact achieved between households and extension agents than membership to extension groups.

Credit

In Mangwende CA, traditionally loans have been taken for maize production. The use of credit has decreased over the years; only 6% of the households obtained loans in 2001, a 20% reduction compared to those who received loans in 1990. In 1995, only 8% obtained loans. Rukuni (1990) reported that the use of credit by the communal area farmers declined after reaching a peak in 1986. Farmers went through several bad seasons, which made them default on loan repayment. Therefore, even though credit was important for maize production on smallholder farms in the mid-eighties, it was no longer

in 2001. Despite the fact that loans are given out by AFC, which charged interest rates that are below open market levels, most farmers indicated that the interest rates charged on the loans are too high, even at 30% per annum, which was even below the rate of inflation.

The loans taken by farmers in 2001 are for groundnut production. The GMB introduced seed and fertilizer loans for groundnut production on a trial basis in 2001. Farmers had to form groups to access the groundnut input loans.

Traditional Methods of Improving Soil Fertility

Farmers are aware of and practice several methods of improving soil fertility that can be considered as traditional, such as crop rotations, plowing the field soon after harvesting, unmanaged fallow (nothing planted in the fields), and using leaf litter and anthill soil (Table 4-17). Winter plowing allows weeds and other biomass in the fields to be incorporated after crops have been harvested. The use of chemical fertilizers and cattle manure are conventional in this case. More than 33% of the households are aware of green manuring, improved fallows and soybeans.

For 83% of the households, the major reason for growing legumes is to produce food. Seventy four percent of the households grow legumes for sale and 19% of the households grow legumes to improve the fertility of the soil. However, improving soil fertility is a secondary objective. In fact, it is likely that these farmers are aware of the advantages of the legume crops to their soil, but have not yet tried to plant the legume with the sole purpose of improving soil fertility. Two percent of the households grow legumes to feed their cattle. Groundnut residues are often fed to cattle or simply thrown into the cattle pen to increase the quantity of manure subsequently harvested, rather than being planted as cattle feed alone.

Table 4-17. Farmers' awareness and use of alternative methods of improving soil fertility.

Technology for improving soil fertility	Percentage of households	
	Aware of technology	Using technology
Rotation	97.0	50.5
Anthill soil	96.0	21.2
Winter plowing	94.9	57.6
Unmanaged fallow	91.9	64.6
Leaf litter	88.9	30.6
Green manuring	49.5	5.1
Soybean	41.4	2.0
Improved fallow	33.3	2.0

Table 4-18. Legume crops that farmers grow.

Crop	Percentage of households[a]
Pigeon Pea	8
Velvet Bean	11
Cow Pea	88
Soybean	22
Field Bean	70
Groundnut	97

[a] More than 100% since some farmers grew more than one crop.

Incorporating biomass from leguminous crops at the right time enhances soil fertility. Farmers were asked to indicate the crops among the legumes in Table 4-19 they can incorporate to improve the fertility of the soils in their fields. Some 69% of the

households are willing to incorporate at least one legume to improve the fertility of their soil.

Table 4-19. Crops farmers are willing to incorporate in their fields to improve soil fertility.

Crop	Percentage of households[a]
Pigeon Pea	5.05
Velvet Bean	8.08
Cow Pea	33.33
Soybean	8.08
Field Bean	9.09
Groundnut	14.14
Sun-hemp	2.02
None	29.00

[a] Does not add up to 100% since some farmers are willing to plant more than one crop.

Cowpea is most preferred for incorporation. Even though cowpea is a food crop, it is not as highly valued as the other crops. Twenty nine percent are not willing to incorporate any crop due to lack of shortage of seeds for re-planting and the need to produce food. Therefore, for these farmers, satisfaction of food security requirements has to be integrated into the assessment of new technologies, such as incorporating crops into the field.

Asked what crops they are willing plant after incorporating, 40% of the households plant legume crops again, such as groundnuts and field beans (Table 4-20). This reveals that farmers do not understand the contribution of legume crops to soil fertility or the concept of crop rotation.

Table 4-20. Crops that households are willing plant after incorporating legume crops.

Crop	Percentage of households[a]
Maize	80.88
Groundnuts	20.59
Field Beans	19.12
Finger Millet	16.18
Bambara groundnuts	4.40
Cotton	4.40

[a] More than 100% since some farmers indicated willingness to plant more than one crop

Conclusion

This chapter shows that smallholder farmers of Mangwende CA are typical of other smallholder farmers. They have limited resource levels, multiple activities and poor service from institutions, such as extension. The amount of fertilizer the households purchase has been decreasing over time, suggesting that farming, which is their lifeline, is under threat. Some of the households are food insecure in some years.

Their farming system is complex as they rely of a variety of activities to sustain their livelihoods. Households engage in crops production where surpluses are marketed. They also depend on members who do not live on the farm for cash and non-cash support.

Characteristics such as number of members in the household, the age and gender of the head of the household, the size of the farm, amount of fertilizer purchased in any year or amount of unmanaged fallow land, number of cattle owned (and the accompanying access to cattle manure) are important at the household level and their levels vary across households. This suggests that technologies are likely to be suitable to the households to varying degrees. Nevertheless, some similarities exist across households. Maize was the

major cash and food crop in the area, and every household planted some. In addition, all households practice dry-land farming.

While the farmers are aware of alternative technologies for improving soil fertility, very few of them use them. This was expected since the technologies have not been on the extension program.

New technologies need to satisfy food and cash requirements since some households experience food shortages over time. Farmers planted crops for food and cash, even though they are aware of the secondary benefits they can derive from the crops, such as enrichment of soil fertility. Green manure technologies, which involve the incorporation of crop residues, should not make households more food insecure or short of cash requirements.

Technologies that might be compatible to different households are needed. However, the diversity between households is likely to make the task difficult. Farmers are compatible with the technologies can be the targets for extension programs promoting the new technologies. Such targeting can partly be achieved using a household LP model that is sensitive to the diverse characteristics of households, and may make provision of extension more efficient and productive. Development of such a model is the subject of Chapter 5.

CHAPTER 5
THE BASELINE HOUSEHOLD LINEAR PROGRAMMING MODEL

This chapter presents results of a household LP model sensitive to the diverse characteristics of households. The LP model is presented in Appendix D.

Subsistence Consumption Requirements

Maize for subsistence requirements is produced on the farm. When households run out of maize, they hire out labor in exchange for maize or buy maize, which they take to local millers for processing. Ideally, households do not buy processed maize meal in retail stores as they consider it less nutritious and expensive. Households have to store their maize from one quarter to the next. As the staple food crop, a minimum level of subsistence requirements has to be met in each quarter. Only dent hybrid maize varieties are grown, which are susceptible to attack by storage pests, so that losses occur during storage. It is estimated that there is a 5% loss of maize in storage per quarter, so that 1,000 kg at the end of one quarter is be reduced to 950 kg in the next quarter.

The quantity of maize that a household requires for subsistence consumption is a factor of the household composition and the level of wealth of the households. Wealthy households are expected to store more maize, thus foregoing immediate receipt of cash, yet securing themselves from possible shortages in the future. The amount of fertilizers and seeds that a household purchases, number of cattle it owns, and the size of the farm, are joint proxies of the level of wealth a household possesses. They are expected to have partial effects on the amount of maize that can be stored. Based on survey data, an ordinary least squares (OLS) regression model to determine partial effects of the

household attributes on maize consumption was developed. The following equation gives maize subsistence requirements for household i: $(MZCONS)_i = B_0 + B_1(FARMEXP)_i + B_2(FSIZE)_i + B_3(CATTLE)_i + B_4(FAMCONS)_i + e_i$. Where: *MZCONS* = Maize consumption (kgs), *FARMEXP* = Farming expenditure; *FSIZE* = Size of the farm (ha)) *CATTLE* = Number of cattle owned; *FAMCONS* = Number of family members above seven years and e is a normally distributed random error term with constant variance, i.e., $e_i \sim N(0, \sigma^2)$. This OLS regression model allows the consumption requirements of any household to be estimated when the households characteristics are known. The results are presented in Table 5-1. The results of the consumption model are incorporated in the LP model.

Table 5-1. OLS Regression results for maize consumption requirements.

Variable	Coefficient	Standard Error of Coefficient	t-significance level
Independent variable: *MZCONS*			
Constant	105.26	131.87	0.43
FARMEXP	0.03	0.008	0.001
FSIZE	86.40	35.90	0.018
CATTLE	18.54	7.71	0.018
FAMCONS	32.78	22.17	0.14

Maize Yields Used in the Model

In addition, a maize yield regression model was developed from survey data. Variables included in the maize yield regression model and the signs expected on their coefficients are presented in Table 5-2. Maize yields are expected to increase as the

amount of fertilizer increases. As the marginal increase in yield from a unit increase in fertilizer is expected to be declining, the square of the quantity of Ammonium Nitrate is expected to have a negative sign. Coefficients for frequency of contact with extension agents, ownership of draft power, are expected to positively affect yield levels. Households with large farms might spread their fertility inputs and management more thinly than those with small farms do, resulting in lower yields on larger farms. Therefore, the coefficient for size of the farm should have a negative sign. In addition, the coefficient for delayed planting should have a negative sign since a delay in planting would result in a fall in yields.

Table 5-2. Variables included in the maize yield regression model.

Variable Name	Variable description	Expected sign of Coefficient
Maize yield in 2001	1,000 kg/ha	Dependent Variable
Ammonium Nitrate	kg ha^{-1}	+
(Ammonium Nitrate)^2	(kg $ha^{-1})^2$	-
Frequency of meeting extension	More than three times per year = 1; Less than three times per year = 0	+
Ownership of Draft Power	Owners = 1; Non-Owners = 0	+
Total farm size	Area (ha)	-
Time of Planting	Planted after 15 December = 0. Planted before 15 December = 1	-

Coefficients of the maize yield regression model are presented in Table 5-3. Maize yields in the LP model are obtained from the yield model. The coefficients in the regression model have the expected signs, except for farm size. However, it is possible that farmers with larger farms also own cattle so can better manage their maize plots, thus

making them realize higher yields than those with smaller farms. The results of the maize yield model are incorporated into the LP model. The yield model allows the management of maize to be varied in the model, using the variables in the maize yield model.

Validation of the LP Model

A five-year LP model was constructed and run for all sample households (n = 99). Five years accommodates the fallow period and the maize following the fallow, for one-year, two-year and three-year fallows. To run the model for each household, dimensions for household, obtained from the questionnaire survey, maize yields simulated from the maize yield regression model and average labor coefficients from group interviews are used.

Table 5-3. Regression coefficients of the maize yields.

Variable	Coefficient	Standard Error	t-Significance level
Ammonium Nitrate[a] (kg/ha)	0.0101	0.0027	0.0002
Ammonium Nitrate $(kg/ha)^2$	-0.0001	0.0001	0.0757
Frequency of meeting extension	0.5680	0.2079	0.0069
Ownership of Draft Power	0.4399	0.2026	0.0313
Total Farm Size (ha)	0.1773	0.9945	0.0762
Time of Planting	-0.5155	0.2539	0.0439
Constant	0.2543	0.3197	0.4275

$R^2 = 0.30$
[a]Ammonium Nitrate is 34.5% Nitrogen.

Validation of the LP model is a continuous process from the time data collection is initiated in the research area. The LP model was constructed progressively as interviews

were conducted to ensure that the model reflected the findings from the surveys. The model in the laptop computer was taken to the farmers. This was to ensure that the model captured the important facets of the livelihoods of farmers in the survey area. Validating the model with farmers involved reminding the farmers about the data collected during the household survey and the group meetings, then explaining that the data is used for constructing a computer model to simulate the activities they conduct on the farm. The farmers were shown the computer model so that they could see the activities households undertake and the resource constraints. The limiting resources and the time when the resources were limiting were indicated to the farmers. The price of fertilizer was then increased and the model would be run with the new prices. The change in activities following the change in fertilizer price was discussed with farmers, in terms of the change in their activities and income for discretionary spending and changes in the resources that were limiting. At each point, farmers either confirmed whether the structure of the model was correct and whether the predicted activities were realistic. When there was a query regarding the model, this was rectified immediately. One area that farmers pointed out was the differentiation of labor. During initial validation, it emerged that some activities are only under taken by a particular gender within the household. This has an important bearing on the activities that the household can undertake. To address this on a wide scale, a supplementary survey was conducted to collect information on differentiation of activities by gender for all households. The computer was particularly instrumental in ensuring that questions and suggestions from farmers about the model can be included in the model and be discussed immediately. The ability of the model to answer the issues raised by farmers was also considered

together with farmers. Overall, farmers were impressed with the results of the model, particularly its ability to determine the times when they experienced labor bottlenecks during the year and what effects changes in prices have on their activities and income.

In addition to validation of the model with farmers, statistical validation was conducted to see how well the model simulated the livelihood systems of the sample households. Model results are compared with survey data. The area under maize, the major crop in the system, and the arable area under unmanaged fallow are used for validation.

Maize Area

It is important to ensure that the area that farmers allocated to maize, the most important crop in the system grown for food and cash, is simulated accurately in the model. Households strive to plant more maize and are forced to reduce the area due to shortages of inputs. The fertility resources they have for improving soil fertility, e.g., chemical fertilizers and cattle manure, are applied on maize. Because maize uses the most chemical fertilizers that farmers purchase, it is also most affected by the failure of farmers to purchase more fertilizers due to the escalation on fertilizer prices.

The areas under maize in the model solutions for the second, fourth and fifth year are not significantly different from the maize area reported during the survey (Table 5-4). Non-significance of the t-statistic means that the means are not statistically different, and this is the desired result. Significant differences occurred in two years out of the five. Correlation coefficients between the areas planted to maize obtained from the model and the survey data are strong for five years.

Land under Unmanaged Fallow

The unmanaged fallow area reflects how farmers meet the resources required to utilize their land and the competitiveness of cropping activities versus non-cropping activities. Shortages of resources, e.g., cash for purchasing seed and fertilizers or labor, compel farmers to have land under unmanaged fallow. Unmanaged fallow land is important with respect to improved fallow technologies assessed in Chapter 6. Unmanaged fallow land can potentially be converted into improved fallows. Therefore, it can be hypothesized that, other things being equal, the size of the area under unmanaged fallow can positively affect the potential adoption of improved fallows. Therefore, it is critical that the model simulates the area under unmanaged fallow on the farm.

Table 5-4. Comparison between average maize area from survey and model data, and their correlation coefficients (n = 96).

Year in model	Maize area (ha) (From model)	t Significance level (Model vs. Survey data)	Correlation coefficient
1	0.89	0.004	0.61
2	1.01	0.120	0.60
3	0.90	0.007	0.53
4	1.32	0.110	0.70
5	1.13	0.800	0.49
Survey data	1.14		

A t-test for comparison of the mean of the arable area under unmanaged fallow in the model and reported in the survey showed that the model closely reflected reality. The area reported to be under unmanaged fallow during the survey is not significantly different from that obtained from the model, in four out of five years (Table 5-5). The

area reported to be under unmanaged fallow during the survey has a strong correlation with the land under unmanaged fallow in the model, showing that farms with large and small areas under unmanaged fallow during the survey also have large and small unmanaged fallow area in the model, respectively.

The validation suggests that the model simulated households well and is adequately robust to be used for determining how households with different characteristics respond to policies and new technological interventions in their livelihood systems. The next section assessed the performance of the households when subjected to a price shock, i.e., an increase in the price of chemical fertilizers.

Table 5-5. Comparison between average unmanaged fallow areas from survey and model data, and their correlation coefficients (n = 94)

Year in model	Unmanaged fallow area (ha) (From model)	t-test significance level (Model versus Survey data)	Correlation coefficient
1	1.21	0.01	0.68
2	0.96	0.90	0.63
3	1.20	0.66	0.06
4	1.00	0.64	0.70
5	1.10	0.65	0.26
Survey data	0.95		

Effects of Increases in Fertilizer Prices on Area under Maize

The validated model is used for asking how households react to increases in fertilizer prices, before the introduction of the improved fallows and green manure.

The liberalization of agriculture in Zimbabwe. Between 1980 and 1991, the government controlled chemical fertilizer prices. After liberalization in 1991, fertilizer

prices changed rapidly, in accordance with the high rate of inflation in the country, particularly in 2000 and 2001. The activities of the government in the marketing of maize limited the prospects for an increase in maize producer prices. The government-announced producer prices remained constant throughout the marketing season. In addition, a law enacted in 2001 made it obligatory for farmers and grain buyers to sell grain directly to the government parastatal, the Grain Marketing Board, and not to manufacturers. Even though the government stated that this was a temporary measure, the policy curtails the ability of the maize producer price to respond to supply and demand conditions in the market. Private grain buyers offered prices below the price they eventually sold to government. Given this scenario, it is reasonable to consider the possible effects of changes in fertilizer prices, holding all other prices constant. Such price changes reflect a short-term position, as all prices are expected to change in the long-term. With such a short run price change, the model was run to determine how households respond to fertilizer price increases, holding other prices constant.

Area planted to maize before change in fertilizer prices. Before the change in the price of fertilizers, owners of draft power plant more maize ($p = 0.0001$), with owners planting 1.3 ha and non-owners planting 0.76 ha. Significant differences in the area planted to maize exist between households with different numbers of members who worked fulltime on the farm ($p = 0.001$). Households with one, two, and three or more workers plant 0.58 ha, 0.95 ha and 1.58 ha, respectively.

Effect of increase of fertilizer prices on maize area. The response of households to the increase in fertilizer prices is determined by changing Z$750, the current average price of Compound D and Ammonium Nitrate fertilizer to Z$825 and to Z$937.5 per 50

kg in the model. The new fertilizer levels represent a 10% and 25% increase in fertilizer prices from Z$750. Following an increase in fertilizer prices, the area under maize is reduced. Fertilizer price increases of 10% resulted in draft owners reducing the area on which manure and chemical fertilizers are used by 0.2 ha and 0.04 ha for owners and non-owners of draft power.

Based on the results of the models, the area under maize is regressed against fertilizer prices and household characteristics. The results of the regression are presented in Table 5-6. They indicate that the area planted to maize falls as the price of fertilizers increase. Starting at a base price of Z$750 for chemical fertilizers, a Z$100 increase in the price of chemical fertilizers results in a 0.1 ha fall in the area planted to maize.

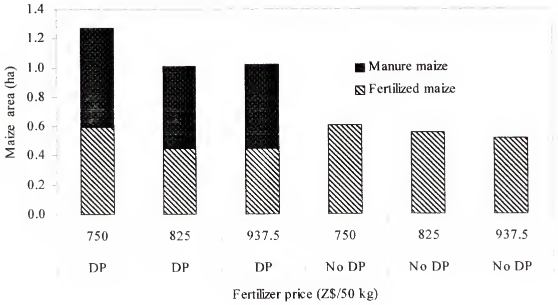

Figure 5-1. Area under maize at different fertilizer prices for owners and non-owners of draft power.

Table 5-6. Regression results of area planted to maize against fertilizer prices and household characteristics, based on LP model results (n = 96)

Variable	B Coefficient	Standard Error of B	t Significance level
FPRICE[a]	-0.0011	0.0003	0.0001
FTW[b]	0.5836	0.0808	0.0001
$(FTW)^2$	-0.0715	0.0124	0.0001
REMT[c]	0.0161	0.0064	0.0116
FSIZE[d]	0.6338	0.0906	0.0001
$(FSIZE)^2$	-0.1229	0.0167	0.0001
DRAFT[e]	-0.6075	0.1271	0.0001
DRAFTxFTW[f]	0.1736	0.0406	0.0001
DRAFTxFSIZE[g]	0.2393	0.0432	0.0001
Constant	-0.0075	0.2739	0.9782

$R^2 = 0.63$

[a]FPRICE = Fertilizer price (Z$/50 kg)
[b]FTW_i = Number of fulltime workers in household i
[c]$REMT_i$ = Cash income (Z$'000) remitted to household i in the second quarter;
[d]$FSIZE_i$ = Farm size in hectares for household i;
[e]$DRAFT_i$ = Dummy variable of ownership of draft power. Where 1 = Owner of draft power and 0 = Non-owner of draft power;
[f]DRAFTxFTW= The product of DRAFT and FTW;
[g]DRAFTxFSIZE = The product of DRAFT and FSIZE;

Household Labor and Ownership of Draft Power.

The area planted to maize tends to increase as the number of members working fulltime on the farm increases. Figure 5-2 shows the differences between households with different numbers of members working fulltime on the farm, distinguishing between owners and non-owners of draft power. Owners of draft power are more responsive to increases in number of fulltime workers, at any fertilizer price level, i.e., they have a greater increase in maize area from a unit increase in number of members working

fulltime on the farm. Ownership of draft power increases the ability of labor to plant more maize.

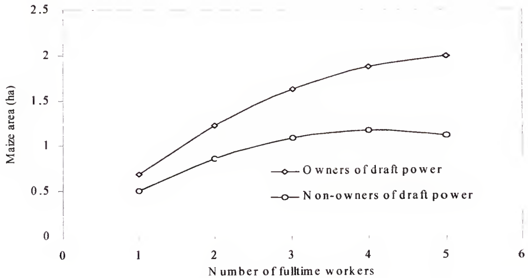

Figure 5-2. Area planted to maize by households with different number of members working fulltime and ownership of draft power.

The area planted to maize increases until the number of fulltime workers reaches five and four for owners and non-owners of draft power, respectively. After this level, other resources and household requirements are likely to be limiting on the area that can be planted to maize. Only 15% of the households have four or more members working fulltime on the farm. Twenty three percent of the households have one member, 41% have two and 22% have three. Therefore, households with three or less labor and average levels of other resources are limited on the area they can plant to maize.

Farm Size and Ownership of Draft Power.

Farm size tends to have a positive effect on the area under maize. The positive interaction term between the size of the farm and ownership of draft power indicates that households with draft power plant more maize at any farm size. The marginal effects of increases in farm size are decreasing (Figure 5-3). Owners of draft power attain a

maximum area under maize when farm size is 3.6 ha while non-owners of draft power reach a maximum when the farm size is 2.6 ha. The average farm size for draft and non-draft owners is 2.7 and 2.3 ha, respectively. Therefore, for owners of draft power with average resources levels, the area under maize is likely to be limited by the sizes of their farms.

Income for Discretionary Spending

The response of household income for discretionary spending to the increase in fertilizer prices is determined by changing the price of fertilizer from the base average of Z$750 to Z$787.5, Z$825 and Z$935.5 per 50 kg in the model. To determine the impact of fertilizer prices on household income, income is regressed against fertilizer prices and household attributes. The results of the regression are presented in Table 5-7.

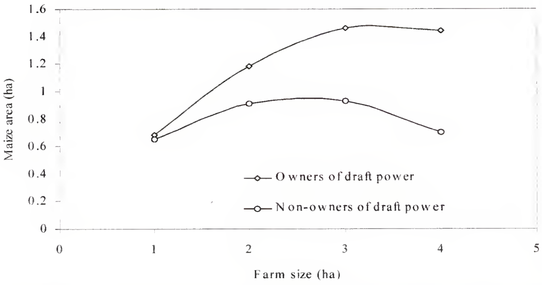

Figure 5-3. Area planted to maize by households with different farm sizes and ownership of draft power.

Household Labor

The income for discretionary spending for owners of draft power is higher than that of non-owners of draft power across all numbers of members working fulltime on the farm

(Figure 5-4). The income increases with increases in the number of members working on the farm. The implication is that death or out migration of a member working fulltime on the farm results in a fall in income. Non-owners of draft power have lower incomes and they can be more vulnerable to the death or migration of fulltime working members.

Table 5-7. Regression results of annual household income for discretionary spending (Z$'000) at different fertilizer prices and household characteristics (n = 99).

Variable	B Coefficient	Standard Error of B	T Significance level
FPRICE[a]	-0.0077	0.0036	0.0355
FTW[b]	7.2076	1.0950	0.0001
$(FTW)^2$	-0.8486	0.1678	0.0001
REMT[c]	3.7388	0.0886	0.0001
FSIZE[d]	6.8858	1.2394	0.0001
$(FSIZE)^2$	-1.4204	0.2310	0.0001
DRAFT[e]	-10.2328	1.7274	0.0001
FERT[f]	0.2059	0.0580	0.0004
DRAFTxFTW[g]	2.4764	0.5512	0.0001
DRAFTxFSIZE[h]	2.6001	0.6135	0.0001
Constant	3.3931	3.7087	0.3608

$R^2 = 0.88$
[a]FPRICE = Fertilizer price (Z$/50 kg)
[b]FTW_i = Number of fulltime workers in household i
[c]$REMT_i$ = Cash income (Z$'000) remitted to household i in the second quarter;
[d]$FSIZE_i$ = Farm size in hectares for household i;
[e]$DRAFT_i$ = 1 for owner of draft power and 0 for non-owner of draft power;
[f]FERT = Number of bags of chemical fertilizer purchased in 2001;
[g]DRAFTxFTW= The product of DRAFT and FTW;
[h]DRAFTxFSIZE = The product of DRAFT and FSIZE.

For owners and non-owners of draft power, income peaks when there are six and four members working fulltime on the farm, respectively. Given that only 15% of the households have four or more members working on the farm, it means that most households have the potential of decreasing their income from a death or out migration of its members.

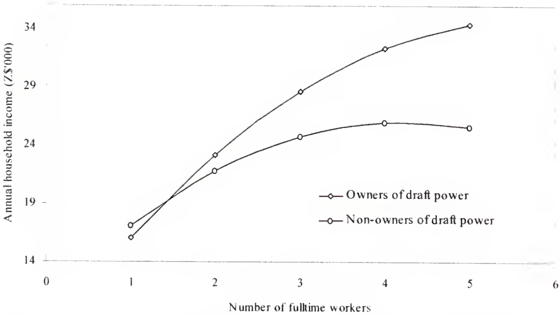

Figure 5-4. Income levels at different number of members working fulltime on the farm and ownership of draft power.

Farm Size and Ownership of Draft Power.

Based on the regression model, on a small farm, say of one hectare, non-owners of draft power have higher income compared to owners. When the size of the farm is more than two hectares, owners of draft power have higher income for discretionary spending than non-owners of draft power. The income for discretionary spending for owners of draft power no longer increases when the size of the farm reaches three hectares. Income for discretionary spending for non-owners of draft power increases as their farm size increases, up to 2.4 ha.

The average farm size is 2.7 and 2.3 ha for owners and non-owners of draft power. Therefore, the incomes for discretionary spending for owners and non-owners of draft power with less that 2.7 and 2.3 ha, respectively, and average endowments of other resources, are likely to be limited by the farm sizes. The income for discretionary spending for owners of draft power is more responsive to changes in the size of the farm. The income levels for households with different farm sizes are presented in Figure 5-5.

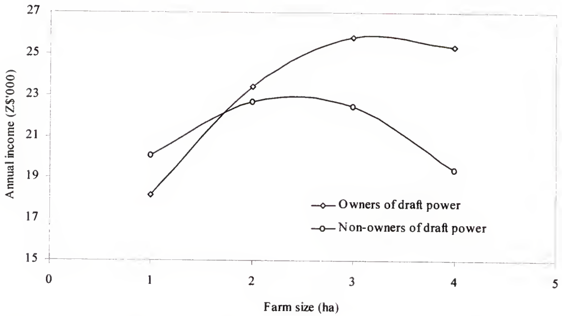

Figure 5-5. Income for discretionary spending at different farm sizes by ownership of draft power.

Effect of Fertilizer Price Increases on Income for Discretionary Spending

Maize is the main cash crop in the system, such that, *ceteris paribus*, a decrease in the area planted to maize translates into a fall in income for discretionary spending. However, other income generating activities that households engage in can become more attractive after fertilizer price increases. In other words, the increase in fertilizer prices is not expected to have a direct impact on income for discretionary spending. A fertilizer price increase is expected to make farmers shift to technologies and activities that require

less fertilizer on maize, but are also likely to have less return. Therefore, the net effect of the increase in fertilizer prices is a decrease in income for discretionary spending. Owners of draft use more fertilizers that non-cattle owners and thus are likely to have a greater fall in incomes.

Overall, the income for discretionary spending decreases significantly ($p = 0.003$) from Z$22,400 to Z$21,600, a 4% reduction, across all households following a 5% increase in fertilizer prices. The income for owners of draft power, which is higher than for non-owners, falls significantly after the increase in fertilizer prices. Income for discretionary spending for owners draft power falls from Z$25,300 to Z$24,400, which is significantly different ($p = 0.001$). On the other hand, the income for non-owners of draft power decreases from Z$17,500 to Z$17,200, which is not statistically significant ($p = 0.4$).

The regression results presented in Table 5-7 indicate that the household incomes for discretionary spending falls as the price of fertilizers increase. On average, increase of Z$100 per 50 kg on chemical fertilizer price results in decreases in household income for discretionary spending of Z$800.

Effects of Death of a Male Head of Household in *de facto* FHHs

The AIDS pandemic is devastating the world, but more so in countries in Southern Africa. It has a serious toll on the urban working class in Zimbabwe. Rural households that rely on cash remitted from working members are likely to suffer after the death of the family members. *De facto* FHHs rely on employed household member(s) for both cash remittances and labor for farming activities. This section explores the effect that the death of the male head of household has on the performance of *de facto* FHHs (which then become *de jure* FHHs). For this assessment, the head of household in *de facto*

FHHs is removed, and then the model is run for the *de facto* FHHs. The results of the model for *de facto* FHHs, with and without the male head, are compared.

LP model results show that the performance of the households depends on the contribution that the male head of household makes to labor and remittances, before death, and the composition of the household that remains after the death. Households in which the head of household has been the only source of male labor and cash remittances experience a fall in income. Households in which other male members working on the farm and the head did not remit cash to the family are not economically affected by the death of the head of household. Forty-two percent of the *de facto* FHHs are in this category. Twenty six percent of *de facto* FHHs do not have cash remitted to them and have more than two males who work on the farm. Some 16% of the *de facto* FHHs have male heads of households who only remit income but do not provide labor for farming activities. Such households do not experience a fall in income after the death of the head of household.

The OLS regression for maize consumption shows that a reduction of family size by one member reduces maize consumption requirements by 33 kg. Therefore, the death of a family member means that resources for producing consumption maize are released and can be made available to other activities.

Results from the LP model show decline in income for discretionary spending for 74% of the *de facto* FHHs. If the males that remain after the death of the head of household are in school, the household does not fare well since school children cannot devote sufficient time to farming activities. Income falls due to a decrease in the area planted to

maize, as it is a cash as well as a subsistence crop. On average, 86% of *de facto* FHHs reduce the area planted to maize and 14% increased the area under maize.

The next chapter uses the LP model developed in this chapter to assess the potential for adoption of improved fallows.

CHAPTER 6
POTENTIAL FOR ADOPTION OF *SESBANIA SESBAN* AND PIGEON PEA IMPROVED FALLOWS

Chapter 5 developed a model to simulate the behavior of smallholder farm households in Mangwende Communal Area (CA). The model was validated in two ways. In the research site, the model was exposed to farmers who gave their input into how close the model represented the construct of their livelihood system. The model was also validated statistically using a diverse sample of households. The two validation procedures showed that the model was robust for use in evaluating the potential behavior of sample households. In this chapter, the model developed in Chapter 5 is used for assessing the potential of diverse households in Mangwende CA, Zimbabwe, adopting *Sesbania sesban* and pigeon pea improved fallows. The potential impacts of increases in the price of fertilizers on household technology adoption are also assessed.

Agroforestry Improved Fallow Technologies and their Potential Adoption

In agroforestry improved fallow technologies, tree species are planted in a crop-fallow rotation. The primary objective is to use the tree species planted in the fallow to fix nitrogen. To utilize the residual soil fertility in the improved fallows, field crops are planted in the fallow after the trees have been removed.

Agroforestry improved fallow technologies are complex with several components that have different developmental cycles, and multiple interactions. Therefore, to ensure the new technologies improve household welfare, the objectives and resources of farmers must be accounted for when assessing the potential adoption of technologies. Since

livestock husbandry, cropping, non-cropping activities, and improved fallows compete for resources within the household, an evaluation of potential adoption of improved fallow technologies also has to consider their contribution to households. This contribution has to be compared to that of activities farmers are already engaged in. To achieve this, in this study, activities of the improved fallow technologies carried out on station experiments are incorporated in the household LP models after validation of the base model (Table 6-1).

Table 6-1. Options of improved fallows introduced into the household LP model.

Year in Model	One year fallow				Two year fallow		Three year fallow
	1.1	1.2	1.3	1.4	2.1	2.2	3.1
1	F				F		F
2	MZ	F			F	F	F
3	MZ	MZ	F		MZ	F	F
4		MZ	MZ	F	MZ	MZ	MZ
5			MZ	MZ		MZ	MZ

F = Year when fallow is in the field; MZ = A maize crop year is in the field.
Fallow notation: Fallow (*j.k*) is a *j* year fallow, planted in year *k*, where $j = 1,2,3$ and $k = 1,2,.., 5$.

One-year fallows can be planted during the first four years of the five-year model. Only two plantings of two-year fallows allow full cycles in the models. Three-year fallows can only be planted in the first year of the five-year model so that maize can be planted on those plots in the fourth and fifth years.

Structural modifications implemented on the base model, to include activities for producing improved fallows and maize following improved fallows, are presented in Appendix E.

Improved fallows are planted at the end of December, the first quarter of the model. In the smallholder farming system, this allows farmers to plant some crops before improved fallows. Nevertheless, activities conducted on improved fallows compete for labor with livestock and cropping activities since farmers need to plant late crops and weed them. *Sesbania sesban* and pigeon pea can be seeded directly into the soil. However, for better establishment, *Sesbania sesban* has to be planted from seedlings, which is recommended and is the approach used in the model.

At the end of the fallow period, trees in the improved fallow plots are cut down and pruned and then their biomass is incorporated by ox-drawn plows. Time required for these operations was recorded on station but is reduced by half in this study since farmers are not meticulous in their pruning of leaves as researchers are inclined to be.

On-station maize yields are likely to be much higher than what farmers realize (CIMMYT, 1988). Therefore, yields realized on experimental plots are reduced by 40% to bring them to yields that farmers are likely to realize in their own fields. This adjustment is supported by the fact that the distribution of the yields reported by farmers during the survey is skewed to the left. Figure 6-1 shows that experimental yields are higher than farmers' yields especially for cowpea green manure. In the figure, A (2,000 kg ha^{-1}) is the average maize yield realized by farmers in 2001, B (3,500 kg ha^{-1}) is the average maize yield following pigeon pea, C (4,500 kg ha^{-1}) is the average maize yield following *Sesbania sesban* and D (5,300 kg ha^{-1}) is the average maize yield following

cowpea green manure on experimental plots. In 1994/95, maize yields on plots grown continuously with maize on station were 2.71 kg ha^{-1} for no fertilizer and 3.3 kg ha^{-1} when 38 kg ha^{-1} of nitrogen was applied.

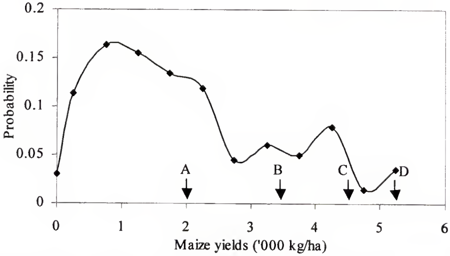

Figure 6-1. Probability distribution of farmers' maize yields (compared to station yields)

Potential Adoption of *Sesbania sesban* Improved Fallow

Based on results of the LP model, households adopt *Sesbania sesban* improved fallow when it is the only technology available or when it is available at the same time as pigeon pea and there is no market for pigeon pea seed. Pigeon pea seeds are not yet marketed in Zimbabwe; therefore, the scenario where pigeon pea seeds are not marketed is the base scenario. Model solutions for scenarios when pigeon pea seeds are marketed at different prices are considered later.

The highest number of households adopts improved fallows in the first year, tailing off over time. In the first year, 81% of the households adopt one-year improved fallows, 51% adopt the two-year improved fallow and 59% adopt the three-year improved fallow. In the second year 12% adopt one-year improved fallow and 5% adopt two-year improved fallow. In the third year, 48% of the households adopt 1-year fallow while

16% adopt 1-year fallow in the fourth year. The area planted to different improved fallows over the first four years of the household LP model is presented in Table 6-2. The three-year fallow is planted in the first year as well. One-year *Sesbania sesban* fallow planted on an average of 0.55 ha, occupying an average of 63% of the area under improved fallow in the first year. One-year fallow planted in the first year is planted to maize during the second and third years. Farmers then plant 0.24 ha of one-year fallow in the third year. The fallow is planted with maize in the fourth and fifth years.

Table 6-2. Area in *Sesbania sesban* improved fallows

Fallow duration	Year			
	1st	2nd	3rd	4th
	Area (ha)			
1-year	0.55	0.04	0.24	0.04
2-year	0.08	0.08	0	0
3-year	0.25	0.25	0.25	0

According to the LP model results, a three-year fallow is also planted in the first year and then planted with maize in the fourth and fifth years. In the first year, the 3-year fallow occupies 28% of the land under improved fallow. In the second year very little improved fallow is planted, so that the 3-year *Sesbania sesban* improved fallow carried over from the first year is the dominant fallow, occupying 68% of the area under *Sesbania sesban* improved fallow. The 3-year *Sesbania sesban* improved fallow constitutes 51% of the area under *Sesbania sesban* fallow in the third year, with the other area being occupied by the 1-year fallow planted in year three. On aggregate, households plant 1.2 ha of *Sesbania sesban* improved fallow in the first four years of the model.

Figure 6.2 shows the fertility management of maize over time, after the introduction of *Sesbania sesban* improved fallow. It compares the maize area planted on land fertilized using the conventional means, i.e., chemical fertilizers and cattle manure, on one hand, and on *Sesbania sesban* improved fallows, on the other. On average, from the second to the fifth year, maize on improved fallow occupies 0.6 ha, which is 60% of the maize area, out of an average farm size of 2.6 ha.

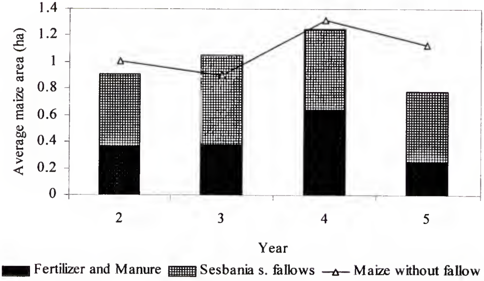

Figure 6-2. Maize area under different soil fertility options over time when *Sesbania sesban* improved fallow is available.

After the introduction of *Sesbania sesban* improved fallow, income for discretionary spending for non-owners of draft power increases significantly ($p = 0.009$) from Z$17,500 to Z$19,400, a 10% increase. The income for discretionary spending for draft power owners increases from Z$24,400 to Z$24,800 after the introduction of *Sesbania sesban* improved fallow. This 2% increase, however, is not statistically significant ($p = 0.6$). Therefore, even though the income of households without draft power remains lower than that for owners of draft power, introduction of *Sesbania sesban* improved fallow is more beneficial to non-owners of draft power than owners.

After the introduction of *Sesbania sesban* improved fallow, income is statistically significantly different between households with one to four members working fulltime on the farm (p = 0.0001). The average annual income for discretionary spending, after the adoption of improved fallows, for households with one member working fulltime on the farm is Z$18,000, while the income for households with two, three and four members working fulltime on the farm is Z$20,000, Z$29,000 and Z$32,000 per annum, resoectively. However, only households with one member working fulltime on the farm experience a significant (p = 0.03) increase in their income for discretionary spending from the introduction of *Sesbania sesban* improved fallow into the system. Therefore, even though *Sesbania sesban* improved fallow can be widely adopted, only households with one member working fulltime on the farm benefit in terms of income for discretionary spending. *De facto* FHHs have the least number of members working on the farm. However, their income remains the lowest across different numbers of household members working fulltime on the farm.

Effects of Household Characteristics on the Area Planted to *Sesbania sesban* Improved Fallows

A regression equation was formulated to determine the partial effects of fertilizer prices and household characteristics on the area planted to *Sesbania sesban* improved fallow in the LP model. Household survey data and fertilizer prices are the independent variables and area planted to *Sesbania sesban* improved fallow in the LP model is the dependent variable, i.e., area under *Sesbania sesban* improved fallow = *f*(Fertilizer prices, labor, size of the farm, remittances received, ownership of draft power, differentiation of labor). Improved fallows demand more labor, such that households with more labor are expected to plant more fallow compared to those with less. Therefore, the coefficient for

number of household members working fulltime on the farm is expected to have a positive sign. Improved fallows substitute for nitrogen fertilizers. Households that receive cash remittances might substitute less of the chemical fertilizers with improved fallows than households that do not receive cash remittances. A variable for cash remittances is expected to have a negative sign on its coefficient. In other words, the more remittances a household receives, the less improved fallows it is inclined to plant. Households need to meet their minimum consumption requirements and cash needs in the years that they plant improved fallows. A household with a small farm does not have much room for including improved fallows compared to a household with a larger land size. Therefore, the coefficient for the farm size is expected to have a positive sign. Some households differentiate labor by gender. Females do not take part in some activities deemed as males and vise versa. This reduces the extent to which all the household labor can be brought to bear on the tasks facing the households. Such households are more likely to be limited by labor in their activities, thus reducing their ability to plant improved fallows. Therefore, the coefficient for differentiation of labor is expected to be negative. Households with cattle and fertilizer are likely to plant less improved fallows than households that do not have cattle manure and fertilizers. Therefore, the interaction term for draft power (cattle manure) and fertilizer is expected to have a negative sign. The regression model results for *Sesbania sesban* improved fallows are presented in Table 6-3.

Number of household members working fulltime on the farm. Regression model results show that the area planted to *Sesbania sesban* improved fallow increases with the number of fulltime workers on the household up to a total of three (Figure 6-3). The

average number of fulltime workers on the farm was between two and three. Only 14% of the households have more than three members working fulltime on the farm. Therefore, for households with average level resources, the number of members working fulltime on the farm limits the area of *Sesbania sesban* improved fallow that it can adopt.

Table 6-3. OLS regression results of aggregate area under *Sesbania sesban* against fertilizer prices and household attributes.

Variable Name	B Coefficient	Standard Error	Significance level
FPRICE[a]	0.0005	0.0004	0.1847
FTW[b]	0.9189	0.1124	0.0001
$(FTW)^2$	-0.1430	0.0196	0.0001
REMT[c]	-0.0546	0.0111	0.0001
FSIZE[d]	1.4620	0.1460	0.0001
$(FSIZE)^2$	-0.2331	0.0271	0.0001
DRAFT[e]	-1.0489	0.1841	0.0001
LABDIFF[f]	-0.2665	0.0635	0.0001
DRAFTxFERT	-0.0187	0.0074	0.0119
DRAFTxFSIZE	0.4080	0.0710	0.0001
De facto FHH[g]	0.0047	0.0837	0.9556
De jure FHH[h]	0.0336	0.0703	0.6326
CONSTANT	-2.0966	0.4106	0.0001

$R^2 = 0.56$

[a]FPRICE = Fertilizer price (Z$/50 kg)

[b]FTW_i = Number of members working fulltime on the farm for household i

[c]$REMT_i$ = Cash income (Z$'000) remitted to household i in the second quarter;

[d]$FSIZE_i$ = Farm size in hectares for household i;

[e]$DRAFT_i$ = Dummy variable of ownership of draft power. Where 1 = Owner of draft power, yes and 0 = Non-owner of draft power;

[f]LABDIFF = 1 when labor is differentiated by gender, 0 when it is not differentiated;

[g]DRAFTxFERT = The product of DRAFT and FERT;

[h]DRAFTxFSIZE = The product of DRAFT and FSIZE;

[g]*De facto* FHH = 1 if *de facto* FHH, 0 otherwise;

[h]*De jure* FHH = 1 if *de jure* FHH, 0 otherwise.

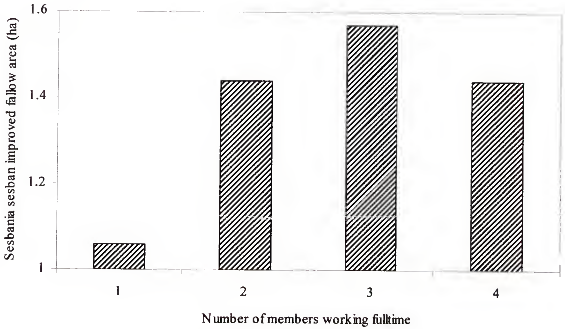

Figure 6-3. Aggregate area planted to *Sesbania sesban* improved fallows over different number of household members working fulltime on the farm

Remittance income. Households with high remittance incomes plant less area under *Sesbania sesban* improved fallows. A Z$100 increase in cash remittances received results in a 550 m^2 reduction in the area planted. This is likely to be due to the ability of these households to purchase fertilizers and thus use less *Sesbania sesban* fallow.

Size of the farm and ownership of draft power. Table 6-4 summarizes LP model results of *Sesbania sesban* improved fallow area planted. Households with larger farms are able to adopt more improved fallows than those with smaller farms. Regression model results show that a marginal increase in the area under fallows decreases as the size of the farm increases (Figure 6-4). At farm sizes less than 3 ha, owners of draft power tend to plant less *Sesbania sesban* improved fallow compared to non-owners. At farm sizes larger than 3 ha, owners of draft power plant more fallow than non-owners. The maximum area allocated to *Sesbania sesban* fallow is attained at different farm sizes

for owners and non-owners of draft power. Owners of draft power plant a maximum *Sesbania sesban* fallow area at 4 ha farm size whereas non-owners of draft power plant a maximum at 3.1 ha. Before the maximum is reached, the size of the farm positively impacts the size of the *Sesbania sesban* improved fallow households adopt.

Table 6-4. Area under *Sesbania sesban* improved fallows adopted by ownership of draft power and farm size.

Range of farm sizes (ha)	Owners of draft power	Non-owners of draft power	Significance level of differences
≤ 2.5 ha	0.73 (0.59)[a]	1.15 (0.65)	0.022
> 2.5 ha	1.70 (0.78)	1.33 (0.71)	0.150
Significance level of differences	0.001	0.480	

[a]In brackets are Standard Deviations

Differentiation of household labor by gender. Fifty three percent of the sampled households differentiated labor by gender. Differentiating labor by gender implies that male labor has specified tasks it carries out, which are different from those for female labor. More households that differentiate labor by gender are limited by labor than those that do not. When labor is limiting, households are less able to adopt improved fallows, as they have less labor available for conducting work on the improved fallows. Households that differentiate labor by gender plant 270 m^2 less *Sesbania sesban* improved fallow than those that do not. Differentiation of labor by gender is an inhibitor to the adoption of *Sesbania sesban* improved fallow.

Draft power and fertilizers. An interaction term for draft power and fertilizers purchased in 2001 also determines the area planted to *Sesbania sesban* improved fallows. Draft power owners plant 200 m^2 less *Sesbania sesban* improved fallow for each

additional bag of fertilizer they have. The result for draft owners suggests that *Sesbania sesban* fallows substitute for fertilizers and cattle manure. When farmers have access to fertilizers, their use of *Sesbania sesban* fallow is reduced. However, the amount of fertilizers that non-owners of draft power have does not affect the area of *Sesbania sesban* improved fallows they plant. Non-owners of draft power do not have access to cattle manure and are more in need of *Sesbania sesban* improved fallow. The area they plant to *Sesbania sesban* improved fallow is independent of the amount of fertilizers they purchased in 2001.

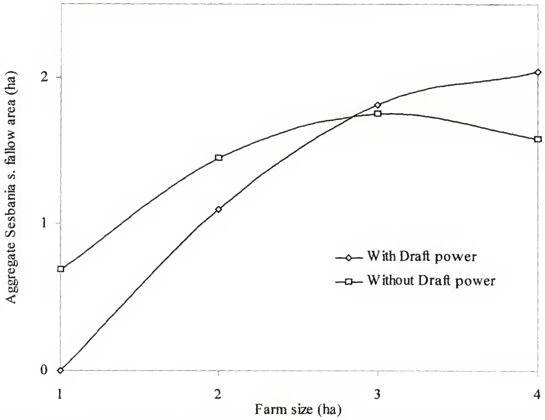

Figure 6-4. Aggregate area planted to *Sesbania sesban* improved fallows over different farm sizes by ownership of draft power

Gender of head of household. Significant differences were observed to exist across MHHs, *de facto* FHHs and *de jure* FHHs with respect to remittance cash income and

percentage of labor that different genders contribute. MHHs have the highest proportion of their labor contributed by males while *de facto* FHHs have more cash remittances. MHHs also have more fulltime workers, even though the F-statistic is only weakly significant. The net result was that *de jure* FHHs emerged as the disadvantaged households across the different parameters.

In Table 6-3, it is shown that taking MHHs as the base, *de facto* FHHs plant the least *Sesbania sesban* improved fallows, i.e., 400 m^2 less than MHHs. *De jure* FHHs plant the largest amount of *Sesbania sesban* improved fallow, i.e., 190 m^2 more than MHHs. However, the coefficients are not significant, implying that statistically there is no difference in the *Sesbania sesban* improved fallow planted across households differentiated by gender of head of household.

Effects of Fertilizer Prices on *Sesbania sesban* Improved Fallows

According to LP model results, 91% of the households adopt *Sesbania sesban* improved fallows over four years when the fertilizer price is Z$750 per bag. The level of adoption increases to 94% when the fertilizer price increases by 25% to Z$937.50 per bag.

LP model results show that the area planted to *Sesbania sesban* at different fertilizer prices increases as the price of fertilizers increases. At Z$750, an average of 1.22 ha of *Sesbania sesban* improved fallow are planted. This increases to 1.23 ha and 1.31 ha at Z$825 and Z$937.50, respectively. The differences are not statistically significant ($p = 0.6$). During the time the survey was conducted, inflation was 60% per annum in Zimbabwe. The inflation rate suggests that the price of fertilizers is going to increase further. However, the coefficient for fertilizer price in the regression model is not significant.

Effects of Household Characteristics on Income for Discretionary Spending

Results of a regression model to determine the effects of household attributes and fertilizer prices on the income for discretionary spending when *Sesbania sesban* improved fallow is adopted in the LP model are presented in Table 6-5.

Members of households working fulltime on the farm. Model results suggest that a unit increase in the number of fulltime workers increases income levels. Income levels obtained in the LP model for households with varying numbers of fulltime workers are presented in Table 6-6. Households with more than three workers have the highest incomes for discretionary spending. In addition, owners of draft power also have higher incomes than non-owners.

Farm size and draft power. Table 6-7 uses LP model results to show the income levels that households with different farm sizes realize. Draft power has a strong impact on income that households have. Overall, owners of draft power have higher incomes that non-owners. For owners of draft power, income for discretionary spending increases with the size of the farm. Non-owners of draft power with farm sizes between 2 and 3 ha have significantly more income ($p = 0.001$) than those with 2 ha or less. There is no significant difference in income ($p = 0.39$) between households with farms of more than 3 ha and those with between 2 and 3 ha. Figure 6-5, obtained from the OLS regression results shows the income levels for owners and non-owners of draft power at different farm sizes.

Gender of Head of Household.

In Table 6-5, MHHs are the base of the three types of households, where *de facto* and *de jure* FHHs are represented with dummy variables in the regression model. The coefficient for *de jure* FHHs is not significant. This means that the income for *de jure*

FHHs is not significantly different from that for MHHs. However, the coefficient for *de facto* FHHs is significant (p = 0.002). The coefficient means that *de facto* FHHs have Z$3,500 more income for discretionary spending than *de jure* or MHHs.

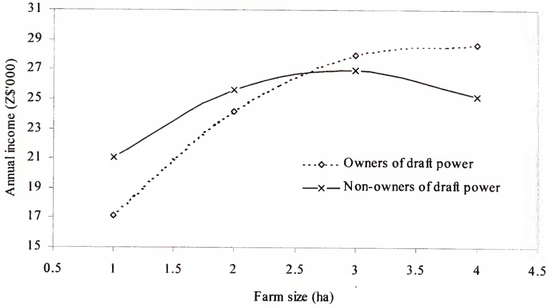

Figure 6-5. Farm discretionary income for owners of draft power at different farm sizes.

Effects of Fertilizer Prices on Income for Discretionary Spending

Adoption of *Sesbania sesban* improved fallows is expected to make households less vulnerable to the adverse effects of increases in fertilizer prices. Regression results suggest that if farmers adopt *Sesbania sesban* improved fallow, increases in fertilizers prices do not have a significant effect on the income for discretionary spending (Table 6-5). *Sesbania sesban* improved fallows offset the effects of fertilizer price increases on income for discretionary spending.

Potential Adoption of Pigeon Pea Improved Fallows with No Market for the Seed

The LP model was also run with one, two and three-year pigeon pea improved fallows as the only options available to the sample farmers. In this scenario, it was assumed that there is no market for pigeon pea seed. Table 6-8, obtained from LP model results,

shows the percentage of households and the average area under pigeon pea improved fallows adopted over five years.

Table 6-5. OLS regression of income against fertilizer price and household attributes (with *Sesbania sesban*).[a]

Variable Name	B Coefficient	Standard Error	Significance level
FPRICE[b]	-1.23	4.87	0.8007
FTW[c]	4348.71	1501.54	0.0040
$(FTW)^2$	-717.89	228.04	0.0018
FSIZE[d]	9294.90	1659.83	0.0001
$(FSIZE)^2$	-1587.95	309.44	0.0001
DRAFT[d]	-11966.05	2374.68	0.0001
FERT[f]	1789.41	185.31	0.0001
DRAFTxFERT[g]	-1258.89	200.51	0.0001
DRAFTxFTW[h]	5730.14	744.35	0.0001
DRAFTxFSIZE[i]	2460.38	824.95	0.0030
De facto FHH[j]	3540.07	946.82	0.0002
De jure FHH[k]	1206.23	798.24	0.1316
CONSTANT	-3981.32	5041.45	0.4302

$R^2 = 0.64$
[a]Official exchange rate: US$1 = Z$55
[b]FPRICE = Fertilizer price (Z$/50 kg);
[c]FTW_i = Number of male and fulltime males in household i
[d]$FSIZE_i$ = Farm size in hectares for household i;
[e]$DRAFT_i$ = 1 if household owns draft power, 0 otherwise;
[f]FERT = Number of bags of chemical fertilizer purchased in 2001;
[g]DRAFTxFERT = The product of DRAFT and FERT;
[h]DRAFTxFTW= The product of DRAFT and FTW;
[i]DRAFTxFSIZE = The product of DRAFT and FSIZE;
[j]*De facto* FHH = 1 if *de facto* FHH, 0 otherwise;
[k]*De jure* FHH = 1 if *de jure* FHH, 0 otherwise.

Table 6-6. Summary of annual income for discretionary spending by draft ownership and number of fulltime workers on the farm

Number of members working s fulltime on the farm	Income for discretionary spending (Z$'000)	
	Owners of draft power	Non-owners of draft power
1	17.9 (6.3)[a]	12.7 (3.5)
2	22.4 (7.4)	15.6 (4.4)
≥ 3	33.8 (11.5)	22.4 (6.5)

[a]In brackets are Standard Deviations

Table 6-7. Income for discretionary spending (Z$'000) over different farm sizes by ownership of draft power.

Farm size (ha)	Owners of draft power	Non-owners of draft power
≤ 2 ha	21.0 (6.2)[a]	13.5 (3.7)
2 - 3 ha	26.5 (11.8)	20.9 (6.2)
> 3	30.6 (10.6)	18.3 (6.4)

[a] In brackets are Standard Deviations

Seventy seven percent and 74% of the households plant the one-year fallows in the first and third year, respectively. Those who adopt improved fallows plant an average of 0.61 ha to one-year fallows in the first year. Households replant the one-year fallow on an average of 0.53 ha in the third year. The rest of the fallows are adopted by lower percentages and are planted on an average of 0.1 ha or less.

Households do not plant the three-year fallow. Therefore, households mainly rely on one-year fallow planted in the first year then planted to maize in the second and third years, and another one-year fallow planted in the third year then planted to maize in the fourth and fifth years. This reliance on the one-year fallows planted in the first and third year was more prevalent for non-owners of draft power than for owners. The difference

between owners and non-owners of draft power in the sequencing of pigeon pea improved fallows is illustrated in Figures 6-6 obtained from the regression model. The major difference between the two groups is that owners of draft power plant 0.3 ha of 1-year fallows in the fourth year, whereas non-owners only plant 0.1 ha. This implies that households plant 1-year pigeon peas fallows every other year. Following this cycle, households continuously have a portion of the farm planted to maize on improved fallows.

Table 6-8. Percentage of households that adopt pigeon pea improved fallows and the average area planted (n = 96).

Years in fallow	Year when fallow is planted	Percentage of farmers adopting	Average area (ha)[a]
1	1	77	0.61
1	2	26	0.05
1	3	74	0.53
1	4	34	0.11
2	1	5	0.01
2	2	20	0.12

[a] For those who adopt some pigeon pea improved fallows over four years

The aggregate area planted to pigeon pea over five years is a function of household level attributes such as number of fulltime workers, the level of remittances received, the size of the farm, ownership of draft power (which also implies ownership of cattle manure), differentiation of labor between by gender, gender of the head of the household. The regression model was specified and results are presented in Table 6-9.

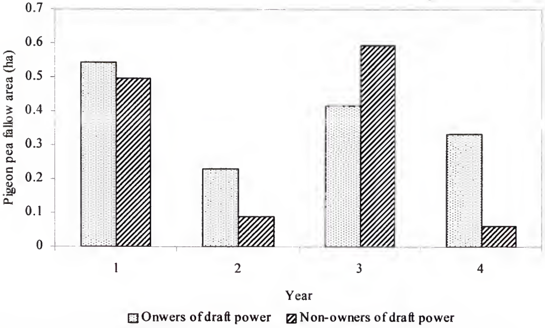

Figure 6-6. Sequence in planting pigeon pea improved fallows by owners and non-owners of draft power

Size of the Farm

Regression results suggest that the size of the farm positively impacts the area planted to pigeon pea improved fallow. The size of the fallow, for owners and non-owners of draft power, increases with the size of the farm. Farm size and draft power have an interaction term which leads to a cross over at a farm size of about 3.8 ha, which is greater than 2.7 ha and 2.3 ha, the average farm sizes for owners and non-owners of draft power (Figure 6-7). At farm sizes below 3.8 ha, non-owners of draft power plant more area to pigeon pea fallows whereas above 3.8 ha, draft power owners plant more pigeon pea improved fallows than non-owners.

The average farm size (2.6 ha) suggests that the potential capacity to plant pigeon pea fallows is likely to be curtailed by the existing sizes of the farms. At the current average farm size, owners and non-owners of draft power plant 0.7 ha and 1.1 ha of pigeon pea fallows per year, respectively.

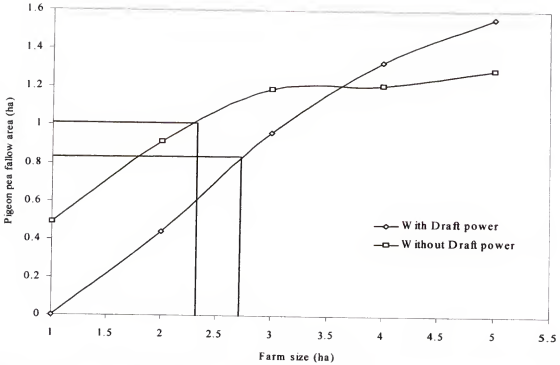

Figure 6-7. Aggregate area planted to pigeon pea improved fallows across different farm sizes, by ownership of draft power (Pigeon pea seed price = 0).

Gender of Head of Household.

In Table 6-9, MHHs are the base of the three types of households, where *de facto* and *de jure* FHHs are represented with dummy variables in the regression model. The coefficient for *de jure* FHHs is statistically significant ($p = 0.03$). This means that *de jure* FHHs plant 0.1 ha less pigeon pea improved fallow than either *de facto* FHHs or MHHs. Considering the coefficient for *de facto* FHHs, whose level of significance is weak when using two-tailed hypothesis testing, it means that there is only a small difference in the area planted to pigeon pea improved fallow between *de facto* and *de jure* FHHs. However, MHHs plant 0.1 ha more pigeon pea improved fallow than either *de facto* or *de jure* FHHs.

Table 6.9. OLS Regression results of area under pigeon pea improves fallow against fertilizer prices and household attributes (n = 96)

Variable Name	B Coefficient	Standard Error	Significance level
FPRICE[a]	0.001	0.0003	0.0011
FTW[b]	0.590	0.0841	0.0001
$(FTW)^2$	-0.105	0.0146	0.0001
REMT[c]	-0.032	0.0080	0.0001
FSIZE[d]	0.643	0.1078	0.0001
$(FSIZE)^2$	-0.074	0.0200	0.0003
DRAFT[e]	-0.967	0.1331	0.0001
DRAFTxFSIZE[f]	0.247	0.0492	0.0001
De facto FHH[g]	-0.105	0.0626	0.0943
De jure FHH[h]	-0.114	0.0519	0.0294
CONSTANT	-1.542	0.3064	0.0001

$R^2 = 0.62$
[a]FPRICE = Fertilizer price (Z$/50 kg);
[b]FTW_i = Number of male and fulltime males in household i;
[c]$REMT_i$ = Cash income (Z$'000) remitted to the household in second quarter;
[d]$FSIZE_i$ = Farm size in hectares for household i;
[e]$DRAFT_i$ = 1 if household owns draft power, 0 = otherwise;
[f]DRAFTxFSIZE = The product of DRAFT and FSIZE;
[g]*De facto* FHH = 1 if *de facto* FHH, 0 otherwise;
[h]*De jure* FHH = 1 if *de jure* FHH, 0 otherwise.

Household Members Working Fulltime on the Farm

The number of household members working fulltime on the farm is expected to increase the area planted to pigeon pea improved fallow. The positive coefficient for number of members working fulltime on the farm in the regression model suggests that households with larger fulltime workforces plant more pigeon pea fallows than those with less. In the LP model, when the average price of chemical fertilizer is Z$750 per 50kg

bag, households with one, two, and three or more members working fulltime on the farm plant 0.43 ha, 0.71 ha and 0.75 ha of pigeon pea improved fallow. The average number of members working fulltime on the farm across the sample is between two and three. However, 64% of the households only have one or two members working fulltime. For these households, labor limits their ability to adopt pigeon pea improved fallows.

The number of fulltime workers on the farm determines the potential adoption and impact of the technology, and thus identifies the households that are likely to benefit from a given technology. Households with fewer fulltime workers have less capability to plant pigeon pea fallow. The number of fulltime working members is an integral part of the definition of the composition of the household. Therefore, household composition, i.e., the size of the household and its makeup, is an important consideration for potential adoption of pigeon pea improved fallow.

Maize Planting when Pigeon Pea Seeds are Not Marketed

Farmers plant combinations of maize using conventional methods of managing soil fertility and maize on pigeon pea improved fallow (Figures 6-8 and 6-9). Owners of draft power plant a maximum of 1.52 ha in the fourth year, while non-owners plant a maximum of 0.66 ha in the third year. For owners of draft power, cattle manure remains an important component of soil fertility management in all years. Non-draft power owners have greater reliance on pigeon pea fallow than cattle owners do. Between the second and fifth years, maize planted on pigeon pea improved fallow occupies an average of 25% of the maize for owners of draft power, while it occupies 70% of the maize planted by non-owners.

Effects of Fertilizer Price Increases on Potential Adoption of Pigeon Pea Improved Fallows

Before an increase in fertilizer prices in the LP model, 74% and 97% of owners and non-owners of draft power adopt pigeon pea fallow, respectively. An increase in the price of fertilizer makes more households adopt pigeon pea improved fallow as reflected by a positive coefficient for fertilizer price in the regression model of area under pigeon pea against fertilizer prices and household characteristics (Table 6-9). The coefficient suggests that, starting from a base price of Z$750, an increase of Z$100 in the price of fertilizer results in an increase of 0.1 ha in the area planted to pigeon pea improved fallow.

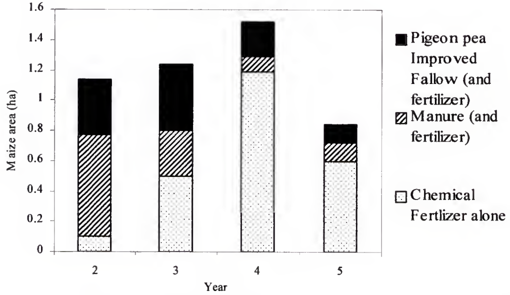

Figure 6-8. Distribution of maize area between conventional and pigeon pea fallows over time for owners of draft power.

In the LP model, a change of fertilizer prices from Z$750 to Z$825 per 50 kg results in all non-owners of draft power adopting pigeon pea improved fallows. At Z$825 and Z$937.5 per 50 kg, 81% and 90% of the owners of draft power adopt pigeon pea improved fallow, respectively. In addition, the area planted to pigeon pea improved

fallow increases as the price of fertilizer increases. Households with more members working fulltime on the farm plant more pigeon pea improved fallow at any fertilizer price (Table 6-10).

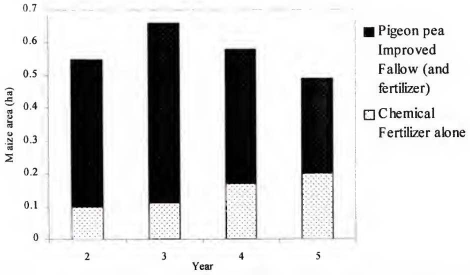

Figure 6-9. Distribution of maize area between conventional and pigeon pea fallows over time for non-owners of draft power.

Households with larger farms plant more pigeon pea improved fallow and plant more improved fallows when the prices of fertilizers increase (Table 6-11).

Substitution of Pigeon Pea for *Sesbania sesban* when Seeds are Marketed

When pigeon pea seeds are not marketed, *Sesbania sesban* dominates pigeon pea. When pigeon pea and *Sesbania sesban* are included in the LP model at varying prices of pigeon pea seed, the area planted to pigeon pea increases as the price of seed increases (Figure 6-10). If both technologies are available and pigeon pea seeds are not marketed, no pigeon pea is planted and 0.26 ha of *Sesbania sesban* improved fallows are planted. The area planted to pigeon pea fallows increases as the price of pigeon pea seed increases. At Z$7,500 for 1,000 kg of pigeon pea seed, 0.35 ha of pigeon pea fallows and 0.01 ha of *Sesbania sesban* are planted per year.

Table 6-10. Area planted to pigeon pea improved fallows by households with different levels of labor and draft power at different fertilizer prices

Number of members working fulltime on the farm	Fertilizer price (Z$/50 kg)		
	750	825	937.5
	Non-owners of draft power		
1	0.49 (0.28)[a]	0.51 (0.28)	0.53 (0.29)
2	0.79 (0.52)	0.84 (0.49)	0.89 (0.51)
≥ 3	1.20 (0.51)	1.22 (0.50)	1.25 (0.53)
	Owners of draft power		
1	0.39 (0.32)	0.49 (0.34)	0.59 (0.31)
2	0.67 (0.58)	0.79 (0.60)	0.93 (0.57)
≥ 3	0.57 (0.71)	0.70 (0.81)	0.82 (0.84)

[a]In brackets are Standard Deviations.

Table 6-11. Area planted to pigeon pea improved fallows by households with different farm sizes and draft power at different fertilizer prices

Farm size (ha)	Fertilizer price (Z$/50 kg)		
	750	825	937.5
	Non-owners of draft power		
< 2	0.51 (0.39)[a]	0.58 (0.28)	0.53 (0.29)
≥ 2-3	1.11 (0.45)	1.13 (0.49)	1.19 (0.47)
≥ 3	1.08 (0.51)	1.08 (0.55)	1.11 (0.59)
	Owners of draft power		
< 2	0.16 (0.25)	0.19 (0.29)	0.27 (0.30)
≥ 2-3	0.42 (0.41)	0.54 (0.47)	0.67 (0.46)
≥ 3	1.06 (0.71)	1.26 (0.59)	1.43 (0.54)

[a]In brackets are Standard Deviations.

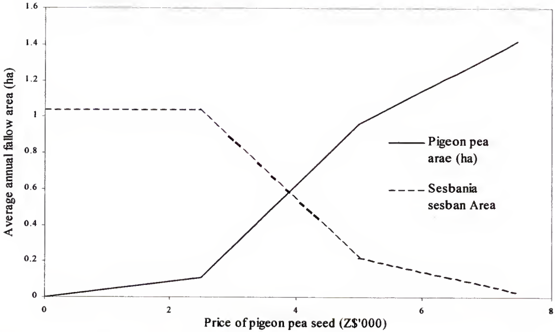

Figure 6-10. Average area planted to *Sesbania sesban* and pigeon pea fallows over 5 years at different pigeon pea seed prices.

No market outlets for pigeon pea seed exist in the communal areas of Zimbabwe. Early adopters of pigeon pea fallows will not be able to market the pigeon pea seeds. However, it is anticipated that, over time, the market outlets might develop as entrepreneurs realize that there are viable quantities that can be marketed. Initially, the government might have to purchase the seed as a way of promoting the use of pigeon pea improved fallow. The government might have to guarantee the price at Z$2,500 as a start. This allows farmers to adopt an average of 0.2 ha of pigeon pea improved fallows.

This chapter looked at the adoption of Sesbania sesban and pigeon pea improved fallows. The effects of increases in fertilizer prices on adoption and income for discretionary spending were also analyzed. Chapter 7 looks at the potential for adoption of cowpea green manure.

CHAPTER 7
POTENTIAL FOR ADOPTION OF COWPEA GREEN MANURE

This chapter uses the model developed in Chapter 5 for assessing the potential of diverse households adopting cowpea green manure. The potential impacts of increases in the price of fertilizers on potential adoption of cowpea green manure are also assessed.

The potential of legumes as green manures has been a subject of considerable research activities in Zimbabwe and elsewhere (Hikwa and Waddington, 1998; Mapfumo at al, 1998, Muza et al., 1998, Gladwin et al., 1997)). Gladwin et al. (1997) specifically raised issues about how to make organic fertilizers more accessible to women farmers. Chibudu (1998b), reported on work conducted with cowpea in Mangwende CA and the results are used in this study. Maize yields in the first year after the green manure were 5300 kg ha^{-1}, with no fertilizer applied (Chibudu, 1998b). These yields were reduced by 40% in the model. Cowpea green manure is available in each of the first four years, allowing maize to be planted in the following year as illustrated in Table 7-1.

The base model was modified to include activities for producing green manure, with maize following the green manure. These modifications are presented in Appendix E.

Potential Adoption of Cowpea Green Manure

When all three technologies, i.e., cowpea green manure, *Sesbania sesban* improved fallows and pigeon pea improved fallows are included in the model, only cowpea green manure are adopted in all years. Even when the price of pigeon pea seeds is increased up to Z$5000, farmers only adopt cowpea green manure.

Table 7-1. Sequence of introducing cowpea green manure in the LP model.

Year in Model	Cowpea green manure			
	1	2	3	4
1	CP			
2	MZ	CP		
3		MZ	CP	
4			MZ	CP
5				MZ

CP = Cowpea green manure; MZ = Maize crop.

Cowpea green manure is a simple technology with high residual effects. All farmers are expected to plant some cowpea green manure, with differences arising due to variation in levels of resources owned. Model results indicate that 96% of all households adopt the cowpea. On average, households plant 0.5 ha in the first two years. This increases to 0.7 ha in the third year and attains a maximum of 0.8 ha in the fourth year, with an average of 0.7 ha across all years. The area under green manure as a proportion of total farm area increases from 27% in the first year to 21%, 34% and 38% in the second, third and fourth year, respectively.

With cowpea green manure available, the area under crops in the first three years is greater than when cowpea green manure is not in the model (Table 7-2). Some of the unmanaged fallow land is put into cowpea green manure, such that the unmanaged fallow area decreases in the first year, then increases over time (Table 7-3).

Over time, the area under cowpea green manure and unmanaged fallow increases (Figure 7-1). Cropped area declines since farmers have to meet the labor required for managing green manure. This means that additional, unmanaged fallow land becomes

available for future cropping. Male labor and female labor limit operations between April and June for 97% of the households (Table 7-4). At this time, households are harvesting cowpea green manure and other crops on the farm.

Table 7-2. Size of cropped area before and after including cowpea in the household model.

Year	Without Cowpea option	With Cowpea option	t-test significance level
1	1.36	1.79	0.0001
2	1.72	2.19	0.0001
3	1.41	1.89	0.0001
4	1.62	1.50	0.0001
5	1.52	1.50	0.0001

Table 7-3. Area under unmanaged fallow before and after including cowpea in the household model.

Year	Without Cowpea option	With Cowpea option	t-test significance level
1	1.24 (1.06)	0.81 (0.93)	0.0001
2	0.88 (1.00)	0.41 (0.54)	0.0001
3	1.17 (1.09)	0.71 (0.83)	0.0001
4	0.97 (1.03)	1.1 (1.03)	0.1300
5	1.07 (1.09)	1.1 (1.08)	0.9000

In brackets are Standard Deviations

More households are constrained by female labor than male labor in the first, second and fourth quarters. As the area under cowpea green manure increases over time, so that

for unmanaged fallow. This is due to the added demand for labor during the third quarter and higher yields realized from maize on green manure.

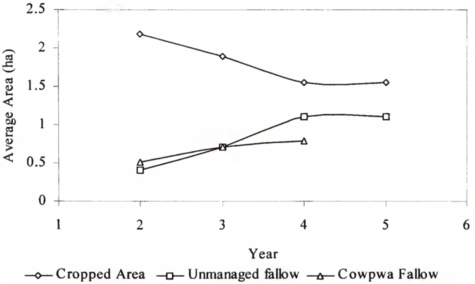

Figure 7-1. Average area under non-green manure crops, unmanaged fallow and cowpea green manure over time.

Table 7-4. Average percentage of households with labor constraints by gender per quarter across all years with cowpea

Quarter	Percentage households with limiting labor	
	Male	Female
October-December	58	91
January-March	70	90
April-June	97	97
July-September	62	81

The cowpea technology results in an increase in household income for discretionary spending. Household annual income increases by Z$5,400 and Z$4,900 for owners and non-owners of draft power. The income increase is significant compared to the income they have before adopting the technology ($p < 0.0001$).

Effects of Household Characteristics on Area Planted to Cowpea Green Manure

The area that farmers plant each year to cowpea green manure is determined by a number of factors. Farmer attributes, e.g., numbers of fulltime workers and different farm sizes influence the area under cowpea green manure. The area under green manure increases as the number of members working fulltime and the size of the farm increase (Tables 7-5 and 7-6).

Table 7-5 Area under cowpea green manure that households of different numbers of fulltime workers plant over four years.

Year	Numbers of fulltime workers			
	1	2	3	≥ 4
1	0.55 (0.16)[a]	0.59 (0.25)	0.71 (0.39)	0.64 (0.55)
2	0.48 (0.15)	0.49 (0.20)	0.59 (0.37)	0.68 (0.56)
3	0.55 (0.26)	0.75 (0.25)	0.99 (0.39)	0.97 (0.54)
4	0.62 (0.22)	0.74 (0.16)	0.94 (0.39)	1.26 (0.49)

[a]In brackets are Standard Deviations

Table 7-6. Area planted to cowpea green manure over four years by households with different farm sizes.

Year	Range of farm sizes (ha)				
	0.75-1.50	1.51-2.5	2.51-3.5	3.51-4.50	≥ 4
1	0.39 (0.30)[a]	0.61 (0.29)	0.65 (0.28)	0.80 (0.32)	0.69 (0.15)
2	0.11 (0.13)	0.50 (0.21)	0.68 (0.27)	0.82 (0.33)	0.71 (0.09)
3	0.53 (0.28)	0.75 (0.33)	0.78 (0.36)	1.02 (0.38)	0.95 (0.16)
4	0.81 (0.22)	0.81 (0.35)	0.85 (0.40)	0.99 (0.39)	0.79 (0.12)

[a]In brackets are Standard Deviations

The area planted to green manure in any year is expected to depend on household resources such as labor, size of the farm, remittances received, and ownership of draft power (which allows use of cattle manure). Based on LP results, a regression equation was formulated to determine effects of household characteristics on the area planted to cowpea green manure. Results are presented in Table 7-7.

Table 7-7. OLS Regression results of area planted to cowpea green manure versus fertilizer prices and household attributes.

Variable Name	B Coefficient	Standard Error	Significance level
FTW[a]	0.1442	0.03539	0.0001
$(FTW)^2$	-0.0309	0.0054	0.0001
REMT[b]	-0.0321	0.0029	0.0001
FSIZE[c]	0.5765	0.0401	0.0001
$(FSIZE)^2$	-0.0874	0.0075	0.0001
DRAFT[d]	-0.4356	0.0567	0.0001
FERT[e]	0.0201	0.0045	0.0001
DRAFTxFERT[f]	-0.0253	0.0048	0.0001
DRAFTxFTW[g]	0.1016	0.0179	0.0001
DRAFTxFSIZE[h]	0.1110	0.0199	0.0001
FPRICE[i]	0.0003	0.0001	0.0090
Constant	-0.6247	0.1202	0.0001

$R^2 = 0.48$

[a]FTW_i = Number of fulltime workers in household i

[b]$REMT2_i$ = Cash income (Z$'000) remitted to household i in the second quarter;

[c]$FSIZE_i$ = Farm size in hectares for household i;

[d]$DRAFT_i$ = 1for owner of draft power, and 0 for non-owner of draft power;

[e]FERT = Number of bags of chemical fertilizer purchased in 2001;

[f]DRAFTxFERT = The product of DRAFT and FERT;

[g]DRAFTxFTW= The product of DRAFT and FTW;

[h]DRAFTxFSIZE = The product of DRAFT and FSIZE;

[i]FPRICE = Fertilizer price (Z$/50 kg).

Number of fulltime working members. The larger the workforce on the farm, the greater the amount of activities the household can accomplish and have some labor available for planting cowpea green manure. Cultivation of cowpea green manure increases the demand for labor during planting since the green manure only produces benefits for the household one season after being planted. The household has to produce its consumption requirements from other plots. Therefore, the number of the family members working fulltime on the farm has a positive impact on the area planted to cowpea in each year. Ownership of draft power interacts with the number of members working fulltime on the farm in determining the area planted to cowpea (Figure 7-2).

Increases in the number of fulltime workers in households with draft power have the effect of increasing the area planted to cowpea green manure. Changes in number of fulltime workers have less impact on the area planted to cowpea green manure in households with no draft power (Figure 7-2). There is a limit on the land that households can plant to cowpea under increasing number of fulltime workers.

For owners of draft power, the area planted to cowpea green manure reaches a peak when household have four members working fulltime on the farm and they plant 0.8 ha. For non-owners of draft power, the area planted to cowpea green manure peaks when the households have between two and three members working fulltime on the farm, and they plant 0.8 ha. Cowpea green manure is planted at the same time when other crops are being planted. Therefore, growing cowpea increases the demand for household resources. The seed from the cowpea in the green manure is harvested and the rest of the crop ploughed into the ground in the third quarter, when harvesting of other field crops is

also carried out. This and the fact that households have a finite amount of resources, results in a limit on the amount of cowpea green manure area a household can establish.

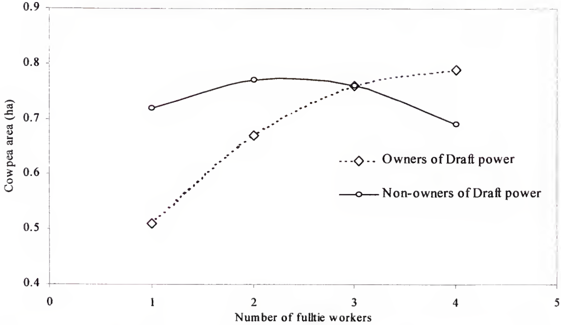

Figure 7-2. Area under cowpea green manure across different number of household members working fulltime on the farm, by draft ownership.

For owners of draft power, young households, *de facto* FHHs, *de jure* FHH and old MHHs, with fewer fulltime workers are likely to adopt smaller areas of cowpea than their counterparts. The significance of the variable for fulltime workers is that family composition will determine the extent to which cowpea will be adopted.

Size of the farm. Households need to use some land for producing food for subsistence requirements and for immediate cash requirements before they allocate land for cowpea green manure. Land for cowpea green manure is likely to be more limiting on small farms, than on larger ones. Therefore, if labor and other resources are equal across farms, households with larger farms allocate more land to cowpea green manure. Owners of draft power have a greater capacity to increase the area they can cultivate and reach a peak in the area planted to green manure at farm sizes of 3.9 ha. Non-owners of

draft power reach a maximum at a lower farm size of 3.2 ha (Figure 7-3). In both cases, the size of the farm at which the peak is reached is greater than the average farm size.

Draft power and fertilizer purchased in 2001. Draft power and fertilizer purchased in 2001 interact in determining the area planted to cowpea green manure. An additional bag of chemical fertilizer increases the area that non-owners of draft power plant to cowpea green manure by 200 m^2. With additional fertilizer, non-owners can transfer some of the land under low yielding maize production into higher yielding fertilized maize, thus making additional land available to plant cowpea green manure. For owners of draft power, an additional bag of chemical fertilizer can be put into additional maize production. However, this does not result in a reduction in the area under cowpeas green manure as they have more resources to work on the additional area under maize.

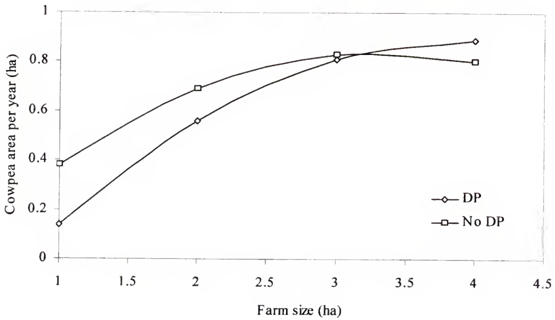

Figure 7-3. Average area planted to cowpea green manure per year on different farm sizes and ownership of draft power.

Cash remittances. Households use the cash remitted to them to contribute to farming expenditures and allow farmers to purchase fertilizers. When cattle manure is used, fertilizer is applied as a top dressing. Therefore, receipt of remittances is expected to allow greater use of fertilizers. Farmers who use fertilizers have less need to plant cowpea for improving soil fertility. Based on the model, cash remittances received between January and March causes a reduction in the area farmers plant to cowpea. An increase of Z$1,000 in remittances result in 0.03 ha reduction in cowpea green manure area per year.

Effects of fertilizer price on area planted to cowpea green manure. Households are expected to increase the area planted to cowpea green manure as the price of fertilizers increases and the profitability of using fertilizer falls, as indicated by the positive coefficient for fertilizer prices. Starting from a base price of Z$750, an increase of Z$100 per 50 kg bag in fertilizer price results in a 300 m^2 increase in the area under cowpea green manure.

Area Planted to Maize Following Adoption of Cowpea Green Manure

The partial effects of fertilizer price increases on the area planted to fertilized maize and/or cattle manure are determined by regressing the area planted to maize in the LP model against the fertilizer prices and variables that determine household attributes. The results of the regression are presented in Table 7-8.

Effect of ownership of draft power and size of the farm. The area planted to all maize increases as the size of the farm increases. A maximum maize area is attained beyond which further increases in the size of the farm leads to a fall in area under maize. Owners of draft power reach the maximum area at a farm size of 3.6 ha, while non-owners reach a maximum at 3.2 ha.

Table 7-8. OLS regression of total maize area against different fertilizer prices and household attributes (when cowpea green manure is in use)

Variable Name	B Coefficient	Standard Error	Significance level
YEAR3[a]	-0.0060	0.0244	0.8046
YEAR4	0.3592	0.0244	0.0001
YEAR5	0.0756	0.0244	0.0020
FPRICE[b]	-0.0004	0.0001	0.0022
FTW[c]	0.3023	0.0411	0.0001
$(FTW)^2$	-0.0379	0.0060	0.0001
REMT[d]	0.0155	0.0030	0.0001
FSIZE[e]	0.5321	0.0416	0.0001
$(FSIZE)^2$	-0.0830	0.0077	0.0001
DRAFT[f]	-0.4568	0.0599	0.0001
LABDIFF[g]	-0.0334	0.0181	0.0654
PMALE[h]	-0.1722	0.0417	0.0001
DRAF TxFTW[i]	0.1934	0.0195	0.0001
DRAFTxFSIZE[j]	0.0745	0.0208	0.0003
CONSTANT	-0.1708	0.1261	0.1756

R2 = 0.55

[a]YEAR3 = 1 if year3, zero otherwise, YEAR4 = 1 if year 4, zero otherwise, YEAR5 = 1 if year 5, zero otherwise;

[b]FPRICE = Fertilizer price (Z$/50 kg)

[c]FTW_i = Number of male and fulltime males in household i

[d]$REMT_i$ = Cash income (Z$'000) remitted to household i in the second quarter;

[e]$FSIZE_i$ = Farm size in hectares for household i;

[f]$DRAFT_i$ = 1 for owners of draft power and 0 for non-owners of draft power;

[g]LABDIFF = 1 when labor is differentiated by gender, 0 when it is not differentiated;

[h]PMALE = Proportion of labor contributed by males.

[i]DRAFTxFTW= The product of DRAFT and FTW;

[j]DRAFTxFSIZE = The product of DRAFT and FSIZE;

The response of owners and non-owners of draft power across farm sizes is illustrated in Figure 7-4. For the same farm size, draft power owners plant more maize.

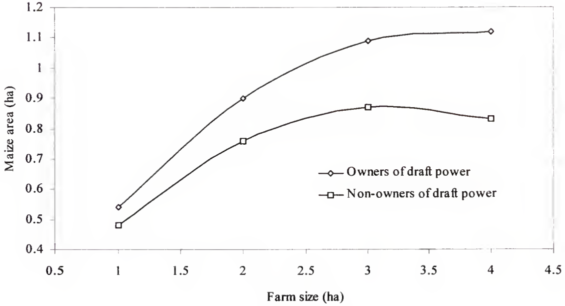

Figure 7-4. Area planted to maize at different farm sizes by owners and non-owners of draft power.

Effect of number of household members working fulltime on the farm. The fulltime workforce on the farm determines the ability of the household to increase the area under maize. The number of working members has a positive effect on the area planted to maize, across different ownership of draft power. Figure 7-5 illustrates the response of households with different numbers of members working fulltime on the farm and draft ownership. Ownership of draft power allows households to plant more maize at all levels of number of members working fulltime on the farm.

Effect of fertilizer prices on total maize area. The coefficient for fertilizer price is not statistically significant (p = 0.8). This means that the area planted to maize does not change in response to changes in the price of fertilizers. This is expected since the proportion of the maize area following pigeon pea green manure is high (Table 7-9).

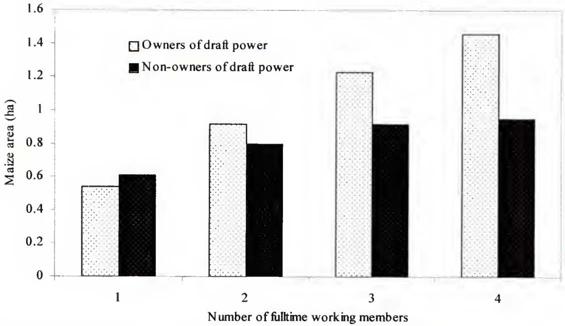

Figure 7-5. Maize area for owners and non-owners of draft power at different number of household members working fulltime on the farm.

Maize Following Green Manure as a Proportion of Total Maize

Figures 7-6 and 7-7 show the proportion of maize planted following cowpea green manure, maize on which chemical fertilizer and/or manure are applied, other crops and cowpea green manure in the second, third, fourth years of the model.

The proportion of area under unmanaged fallow increases over time. In the first year of the LP model, households plant cowpea green manure while producing maize using chemical fertilizers and manure for fertility. Maize planted in the second year on land on which cowpea green manure was planted in the first year allows some resources previously used on original technologies to be released. Land released from the less productive technologies is then used on cowpea green manure. Owners and non-owners of draft power allocate about 20% and 25% of their land to production of green manure, respectively. Non-owners of draft power are expected to allocate a larger proportion of land to cowpea green manure since they do not have access to cattle manure. Indeed, the

non-owners of draft power allocate 90% of their maize to cowpea green manure by the fourth year compared to 63% for owners of draft power.

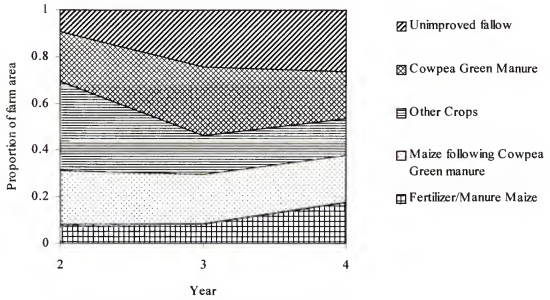

Figure 7-6. Allocation of land to maize, other crops, cowpea green manure and unimproved fallows by owners of draft power.

Number of members working fulltime on the farm. The area planted to cowpea is positively influenced by the number of fulltime workers in the household. The number of household members working fulltime on the farm is negatively correlated with the proportion of maize area planted following on cowpea green manure (Table 7-9).

This means that households with more members working fulltime on the farm have a smaller proportion of their maize following cowpea green manure in any year. Households with more members working fulltime on the farm plant more of both maize on cowpea green manure and other maize than those with less members. In relative terms, households with more members working fulltime on the farm make more use of other technologies, e.g., fertilized maize and manure, compared to those with fewer members. The proportion of all maize occupied by maize following cowpea green

manure was regressed against farm size, ownership of draft power and labor force available on the farm (Table 7-10). Regression results suggest that the number of members working fulltime on the farm only influences the proportion of maize on cowpea green manure for owners of draft power. An increase in the size of the fulltime workforce decreases the proportion under maize following cowpea green manure for owners of draft power. This is illustrated in Figure 7-8.

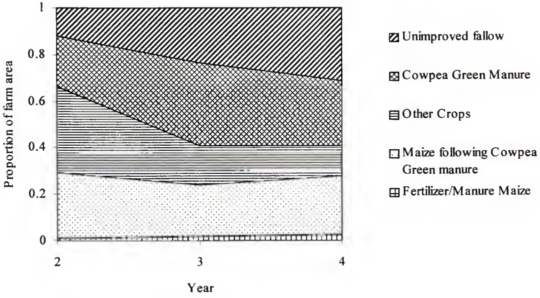

Figure 7-7. Allocation of land to maize, other crops, cowpea green manure and unimproved fallows by non-owners of draft power.

Size of the farm. The size of the farm has a positive effect on the proportion of maize area planted on cowpea green manure. Owners of draft power have a greater increase in proportion of maize on cowpea green manure from an increase in the farm size than non-owners. As the size of the farm increases, a peak in the proportion of maize under cowpea green manure is reached after which further increases in size of farm results in a decline in proportion. For owners and non-owners, the peak is reached when the farm size is 4.4 ha and 3.3 ha, respectively. In both cases, this is greater than the average farm

size for each category. For households with average resource levels, the size of the farm is likely to limit the ability of the households to increase the proportion of maize following cowpea green manure. Households that do not own draft power have a bigger proportion of maize following cowpea green manure than owners of draft power (Figure 7-9).

Table 7-9. Correlation coefficients between number of fulltime workers and proportion of maize following cowpea green manure across years.

Year	Correlation coefficient
2	- 0.55
3	- 0.31
4	- 0.45
5	- 0.31

Income Following Adoption of Cowpea Green Manure

The change in incomes can be expected to depend on a vector of household attributes and the prices of fertilizers. The regression results of the average household income against fertilizers the price and household attributes are presented in Table 7-11. The results suggest that draft power interacts with farm sizes, number of households working fulltime on the farm and the amount of fertilizers purchased, in determining the level of income in the household.

Number of household members working fulltime on the farm. The number of household members working fulltime on the farm positively impacts household income following the adoption of cowpea green manure. In addition, ownership of draft power

results in higher income for discretionary spending across households of different number of members working fulltime on the farm (Table 7-12).

Table 7-10. OLS regression results of proportion of maize area planted on cowpea green manure area.

Variable Name	B Coefficient	Standard Error	Significance level
Dummy 1[a]	-0.5076	0.0256	0.0001
Dummy 2[b]	0.0836	0.0256	0.0012
FSIZE[c]	0.0945	0.0473	0.0469
$(FSIZE)^2$	-0.0146	0.0083	0.0792
DRAFTxFTW[d]	-0.1094	0.0111	0.0001
DRAFTxFSIZE[e]	0.0344	0.0122	0.0053
Constant	0.7235	0.0628	0.0001

$R^2 = 0.74$[a]
Dummy 1= 1 for planting in year 2, zero otherwise;
[b]Dummy 2 = 1 for planting in year 3, zero otherwise;
[c]$FSIZE_i$ = Farm size in hectares for household i;
[d]DRAFTxFTW= The product of DRAFT and FTW where FTW_i = Number of male and fulltime males in household i, and $DRAFT_i$ = 1 for owners of draft power, and 0 for non-owners of draft power;
[e]DRAFTxFSIZE = The product of DRAFT and FSIZE.

Size of the farm. The size of the farm positively impacts the income of households with draft power. There is no significant difference in the income of households without draft power across different farm sizes (Table 7-13). This suggests that only owners of draft power are able to capitalize on the size of their farms to increase income for discretionary spending.

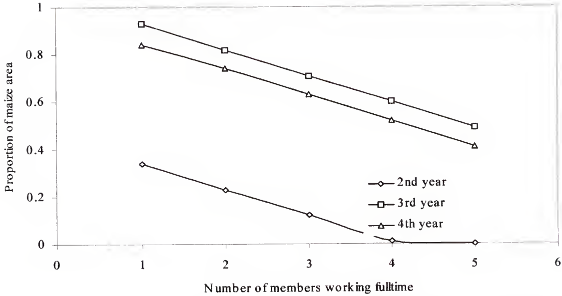

Figure 7-8. Proportion of maize on cowpea green manure for households with different number of members working fulltime on the farm over time for owners of draft power.

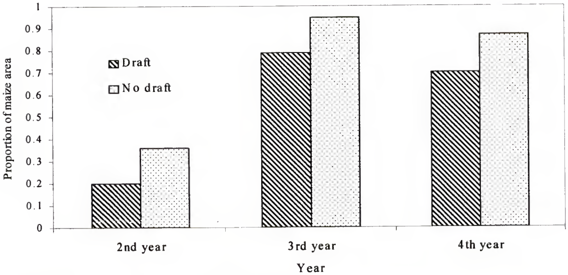

Figure 7-9. Proportion of maize following cowpea green manure for owners and non-owners of draft power over time (on a 2.57 ha farm).

Effect of fertilizer prices on household incomes. An increase in the price of fertilizers is expected to reduce household income. However, the average income levels are not significantly different at the different fertilizer price levels (Table 7-14). The coefficient is not significant in the regression model, suggesting that income does not

change significantly due to changes in fertilizer prices when households are using cowpea green manure. In other words, the cowpea green manure buffers households from fertilizer price changes.

Table 7-11. OLS regression results of income for discretionary spending and household attributes (when cowpea green manure is in use).

Variable Name	B Coefficient	Standard Error	Significance level
FPRICE[a]	-5.765	3.933	0.1435
FTW[b]	4526.943	1182.985	0.0002
$(FTW)^2$	-623.356	182.053	0.0007
REMT[c]	1492.081	98.263	0.0001
FSIZE[d]	10141.611	1339.576	0.0001
$(FSIZE)^2$	-1662.587	249.730	0.0001
DRAFT[e]	-11735.918	1896.065	0.0001
FERT[f]	1312.702	150.195	0.0001
DRAFTxFERT[g]	-928.965	161.700	0.0001
DRAFTxFTW[h]	4670.466	599.065	0.0001
DRAFTxFSIZE[i]	2485.471	665.022	0.0002
Constant	1813.748	4018.789	0.6520

$R^2 = 0.77$

[a]FPRICE = Fertilizer price (Z$/50 kg)

[b]FTW_i = Number of male and fulltime males in household i

[c]$REMT2_i$ = Cash income (Z$'000) remitted to household i in the second quarter;

[d]$FSIZE_i$ = Farm size in hectares for household i;

[e]$DRAFT_i$ = Dummy variable of ownership of draft power. Where 1 = Owner of draft power and 0 = Non-owner of draft power;

[f]FERT = Number of bags of chemical fertilizer purchased in 2001;DRAFTxFERT

[g]DRAFTxFTW= The product of DRAFT and FTW;

[h]DRAFTxFSIZE = The product of DRAFT and FSIZE.

In this chapter, it has been shown that there is potential of pigeon pea improved fallows being adopted. The technology buffers household income from increases in price of fertilizer. Chapter 8, which is the last, presents a summary, conclusions recommendations and limitations of the dissertation.

Table 7-12. Average household income for discretionary spending at different number of members working fulltime on the farm and ownership of draft power

Number of members working fulltime	Income for discretionary spending (Z$'000)		Significance level of differences
	Owners of draft power	Non-owners of draft power	
≤ 2	22.7 (7.4)[a]	18.7 (9.9)	0.001
≥ 3	35.8 (11.4)	25.8 (6.8)	0.001
Significance level of differences	0.001	0.001	

[a]In brackets are Standard deviations

Table 7-13. Average household income for discretionary spending at different farm sizes and ownership of draft power

Farm sizes (ha)	Income for discretionary spending (Z$'000)		Significance level of differences
	Owners of draft power	Non-owners of draft power	
≤ 2.5	23.1 (7.9)[a]	20.2 (11.0)	0.03
> 2.5	32.9 (11.8)	21.8 (6.3)	0.001
Significance level of differences	0.001	0.28	

[a]In brackets are Standard deviations

Table 7-14. Average household income for discretionary spending per year at different fertilizer prices.

Fertilizer price (Z$/50 kg)	Average annual income (Z$'000)
750.0	26.1 (11.3)[a]
787.5	25.5 (11.3)
825.0	25.2 (11.2)
937.5	24.9 (11.1)

F significance level = 0.89
[a]In brackets are Standard Deviations

CHAPTER 8
CONCLUSIONS AND RECOMMENDATIONS

Overview of Study

The major challenges facing the government of Zimbabwe are to improve food security, income levels and the standard of living of its population, particularly for those living on smallholder farms. In Mangwende Communal Area, one of the avenues for achieving these objectives is to improve the yield of maize, the major food and cash crop. Farmers' ability to use chemical fertilizer has declined since the government liberalized the marketing of agricultural inputs in 1991. Researchers have experimented with improved fallows and green manure as possible alternatives or complements for chemical fertilizer. The likely adoption of these technologies in the target areas in Zimbabwe is not known. This study assesses the potential for the technologies to be adopted by diverse farmers in Mangwende Communal Area, one of the target areas for the technologies. The study is unique in that, as an *ex ante* adoption assessment, it assesses the potential that the technologies have when eventually extended to the farmers. It indicates whether the technologies, considered at a whole farm level, will benefit the farmers. Ninety-nine households randomly selected from three wards in Mangwende Communal Area provided data for the study.

Summary of Findings

The Livelihood Systems on Smallholder Farms

Smallholder farmers in Mangwende CA have limited resource levels, are diverse and operate complex livelihoods with multiple activities. Households rely on crop, and non-

crop activities, including livestock husbandry. Crop output surplus to subsistence requirements is marketed.

The composition of households determines their behavior. The average household size was six members, ranging from one to ten. Between two and three members of the household worked fulltime on the farm. Sixty four percent of the households had children that were not yet participating in farming activities. Fifty percent of the households were headed by resident males, 30% were *de jure* FHHs, and 20% were *de facto* FHHs. Labor was differentiated by gender during farming operations in 52% of the households. Farms were small, with an average size of 2.6 ha and a minimum and maximum of 0.75 and 5 ha. Sixty percent had gardens that were large enough for planting maize, but all grew maize in larger plots.

Cattle provided manure used for improving soil fertility and draft power. Fifty five percent of the sample had adequate draft animals to make a span. Draft power also could be hired at a charge.

Crops were planted for food and cash. In 2001, maize and groundnuts occupied 53% and 20% of the area under crops, respectively. All households grew maize. Ownership of draft power increased the ability to plant crops. Draft power owners planted 1.92 ha to crops and 1.14 ha to maize. The total crop and maize area that owners of draft power planted was 60% more than for non-owners of draft power.

Ninety three percent of the households used chemical fertilizer in 2001. Fertilizer use was declining; fertilizer purchased in 2001 was 48% less than in 1990. Owners and non-owners of draft power bought 440 kg and 180 kg of chemical fertilizers, respectively. Farmers applied 38% and 58% of recommended fertilizer rates for basal and topdressing,

respectively. Households had some land under unmanaged fallow mainly due to shortage of chemical fertilizer. The area under unmanaged fallow increased from 0.3 ha to 0.9 ha for owners of draft power and from 0.7 to 1.1 ha for non-owners in 1990 and 2001, respectively.

Some households were vulnerable to food insecurity in some years, with non-owners of draft power being more prone to shortage of food. Over the period 1996-2000, 25% and 58% of owners and non-owners of draft power experienced food shortages, respectively.

Members living way from the farm often remitted cash income. Sixty three percent, 53% and 32% of *de facto* FHHs, *de jure* FHHs and MHHs received cash remittances. Remittances could be used for purchasing chemical fertilizers.

Only 39% of the households had contact with extension agents. Membership in agricultural extension groups did not guarantee contact with extension agents. Sources of credit were limited. Infrastructure, particularly roads, was in a deplorable state.

The Base Household Linear Programming Model

A five-year LP model to simulate the farming systems on smallholder farms was developed and validated. An increase in fertilizer prices resulted in a reduction in the area under maize and income for discretionary spending. An increase of Z$100 per 50 kg on chemical fertilizers resulted in a 0.1 ha fall in the area planted to maize and a fall of Z$800 in household income for discretionary spending.

The effect of the death of a male head in a *de facto* FHH depended on the contribution of labor and remittances that the head of household was making before death, and the composition of the household after the death.

Potential Adoption of Improved Fallows

The potential adoption of *Sesbania sesban* and pigeon pea improved fallows was assessed using the household LP model. The potential adoption of improved fallows depended on the composition of the household, farm size and draft power (farmers with draft power also had access to cattle manure). Adoption of improved fallows increased the household income for discretionary spending. The percentage increase in the incomes of the less resource-endowed households was greater than for the better-endowed households.

Sesbania sesban improved fallows. When pigeon pea seed was not marketed, only *Sesbania sesban* improved fallows were adopted. The adoption of *Sesbania sesban* improved fallows was highest in the first year, declining in later years. In the first year, 81% of the households adopted one-year fallows. On aggregate, households planted 1.2 ha of *Sesbania sesban* improved fallows in the first four years of the model. From the second to the fifth year, maize on improved fallow occupied 0.6 ha, which was 60% of the maize area. The area planted to *Sesbania sesban* improved fallow across households with different gender of head of household was not significantly different.

Following adoption of *Sesbania sesban* improved fallows, annual income for discretionary spending for owners and non-owners of draft power increased by 10% and 2%, respectively. The amount of labor on the farm had a positive impact on income for discretionary spending. The income for households with one member working fulltime on the farm increased significantly following the introduction of *Sesbania sesban* improved fallows. *De facto* FHHs received Z$3,500 more income for discretionary spending than *de jure* or MHHs.

Pigeon pea improved fallows. When *Sesbania sesban* and pigeon pea improved fallows were available to farmers and pigeon pea seeds were not marketed, only *Sesbania sesban* improved fallows were adopted. Pigeon pea fallow was only adopted together with *Sesbania sesban* improved fallow when there was a price for its seed pigeon pea seed.

When pigeon pea improved fallows were the only improved fallow available, even with no market for pigeon pea seed, three quarters of the households pigeon pea adopted fallow. Households relied on 1-year fallow and on average, planted 0.53 ha in the first year and 0.46 ha in the third year. Fallows of other durations were planted on 0.1 ha or less and the three-year fallow was not adopted. Small differences existed between *de facto* and *de jure* FHHs in the area planted to pigeon pea improved fallows. MHHs planted 0.1 ha more pigeon pea improved fallows than either *de facto* or *de jure* FHHs.

When both pigeon pea and *Sesbania sesban* were included in the LP model at varying prices of pigeon pea seed, the area planted to pigeon pea improved fallow increased with the price of seed. When pigeon pea seed was priced at Z$2500, farmers adopted 0.2 ha of pigeon pea improved fallow.

Potential Adoption of Cowpea Green Manure. When cowpea green manure, *Sesbania sesban* improved fallow and pigeon pea improved fallow were available to farmers, only cowpea green manure are adopted in all years. Even when the price of pigeon pea seeds is increased up to Z$5000, farmers only adopt cowpea green manure.

Households with more members working fulltime on the farm and larger farms also adopted more cowpea green manure. Non-owners of draft power planted more green manure. The composition of the household, as reflected in the number of members

working fulltime on the farm, was a key to determining the adoption and impact of green manure.

Adoption of green manure increased the income available to households for discretionary spending. Even though the income for better-endowed households was higher than that of the less endowed households, the income of the less resource-endowed households increased by a higher percentage than that of the better-endowed households. This means that the technology uplifted the well being of the poor households more than for the well off households.

Effects of Fertilizer Price Changes

***Sesbania sesban* improved fallows.** Fertilizer price increases were one of the major risks confronting smallholder farmers given the hyperinflation in Zimbabwe. A 25% increase in the price of fertilizer increased the adoption percentage of *Sesbania sesban* fallows from 90% to 94% and increased the area planted to improved fallows. An increase of Z$100 per bag resulted in a 0.3 ha increase in the improved fallow area. Given the inflation rate in Zimbabwe, this suggests that the area that could potentially be planted to *Sesbania sesban* fallows is likely to increase.

Pigeon pea improved fallows. Before an increase in fertilizer prices, 74% and 97% of owners and non-owners adopted pigeon pea fallows, respectively. Increases in the price of chemical fertilizers positively impacted the level of adoption of pigeon pea improved fallow. A 10% increase in the price of fertilizer resulted in all non-owners of draft power adopting pigeon pea improved fallow. Ninety percent of the owners of draft power adopted pigeon pea improved fallow after a 25% increase in the price of fertilizer. The area planted to pigeon pea improved fallows increased as the price of fertilizers

increased. An increase of Z$100 in the price of fertilizer resulted in an increase of 0.01 ha in the area planted to pigeon pea improved fallow.

Cowpea green manure. Households increased the area planted to cowpea green manure as the price of fertilizer increased. An increase of Z$100 per 50 kg bag in fertilizer price resulted in a 0.03 ha increase in the area under cowpea green manure. Increases in fertilizer prices reduced the relative profitability of maize produced using fertilizers. When farmers adopted cowpea green manure, an increase of Z$100 per 50kg in the price of fertilizers resulted in a 0.09 ha fall in the fertilized maize area. An increase in the price of fertilizers was expected to reduce household income. However, the average income levels were not significantly different at the different fertilizer price levels, i.e., making incomes less volatile, suggesting that cowpea green manure buffered households from fertilizer price changes.

Conclusions

Characteristics such as size of the household, the size of the farm, ownership of draft power (and access to cattle manure) were important determinants of adoption of improved fallows.

Without Improved Fallows and Green Manure

- Land area was not the factor that limited the ability of households to increase their incomes for discretionary spending.
- Income for discretionary spending was sensitive to fertilizer price changes.
- Maize area was reduced due to fertilizer price increases.

With Improved Fallows and Green Manure

- Cowpea green manure was preferred for adoption over *Sesbania sesban* and pigeon pea improved fallows, when the three technologies were available to farmers at the same time.

- When both *Sesbania sesban* and pigeon pea improved fallows were offered to farmers at the same time, a market for pigeon pea seeds was needed for farmers to adopt pigeon pea improved fallow.
- The adoption of improved fallows or green manure buffered income for discretionary spending from the negative effects of increases in fertilizer prices. Income did not change significantly due to changes in fertilizer prices following the adoption of improved fallows and green manure.
- Improved fallows benefited non-owners of draft power more than owners.
- Households with limited resources benefited more from the technologies than the better endowed ones. Even though *Sesbania sesban* improved fallow could be widely adopted, only households with one member working fulltime on the farm benefited in terms of income for discretionary spending. The percentage increase in the income for discretionary spending of non-owners, i.e., the poorer households, following adoption of improved fallows and green manure was larger than for owners of draft power. However, their income remained the lowest across different numbers of household members working fulltime on the farm.
- Household composition, i.e., the size of the household and its makeup, was an important consideration for potential adoption of pigeon pea improved fallow. Therefore, adoption levels were diverse across households.
- Differentiation of labor by gender within a household limited adoption of improved fallows.
- In households with the average level of resources, the number of members working fulltime on the farm limited the area of improved fallows and green manure that households adopted. In households with the average level of resources, the size of the farm limited adoption of improved fallow and green manure.
- Households with larger farms adopted more improved fallow than those with smaller farms. On large farms, owners of draft power adopted more green manure and had more income for discretionary spending than non-owners of draft power.
- With increases in prices of chemical fertilizer, farmers increased adoption of improved fallows and green manure. An increase in the price of chemical fertilizers also increased the adoption of pigeon pea improved fallow.
- When adopting pigeon pea improved fallow, households relied on one-year fallow planted every other year. In the LP model, pigeon pea improved fallow was planted in the first year and planted to maize in the second and third years. Another fallow was planted in the third year, and planted to maize in the fourth and fifth years.

- Receipt of remittances was a disincentive for farmers to adopt improved fallows and green manures.
- Households that do not own draft power planted more cowpea green manure when one or two members worked fulltime on the farm. In larger households, i.e., with more than three members working fulltime on the farm, owners of draft power planted more green manure.
- At farm sizes below 3.8 ha, non-owners of draft power planted more pigeon pea fallows whereas above 3.8 ha, draft power owners planted more pigeon pea improved fallow than non-owners.

Recommendations from the Study

The results from this study show that under the current economic and social circumstances facing smallholder farm households in Zimbabwe, there is potential for improved fallow and green manure technologies being adopted. Given the high rate of inflation in the country and the absence of a mechanism to subsidize chemical fertilizer, fertilizer prices are going to continue rising. Study findings suggest that the percentage of adopters and the area under fallows could also increase. Therefore, these technologies should be extended to smallholder farmers.

Prices used in the LP model need to be updated periodically depending on the rate of inflation that farmers face. In a situation of hyperinflation, as obtaining in Zimbabwe, the interval for updating the prices could be every week.

The development of the model is a process; more information is added as it becomes available. Farmers can participate in the development of the model to improve how the model simulates their livelihoods. This participatory approach makes the researchers and the farmers confident in the results generated by such models.

Improved fallows should be allowed to complement the resources farmers are already using, rather than competing with the resources. This study shows that, among other factors, draft power (which also means access to cattle manure) determines adoption of

improved fallows, yet experimental work has not included manure use into the technologies using improved fallows. The experimental design assumes that farmers do not use chemical fertilizers in combination with manure and improved fallows. The possibility of farmers bringing the three sources of fertility to one plot was not considered in experimental work.

Limitations of the Study

This study is based on a survey conducted in Mangwende Communal Area, which is representative of CAs in NR2 and some in NR 3. However, Mangwende Communal Area may not be representative of the drier areas in NR 4 and 5 where smallholder farmers are also located. Mangwende was used because it is where some of the technologies were tested and it had similar agro-ecological characteristics as Domboshawa Training Center where station experiments were conducted. The performance of these technologies may not be the same in NR 4 and NR 5.

The approach used in this study can be used for developing a base model for the drier areas, i.e. NR 4 and 5. Technologies that may be considered appropriate for the areas can be incorporated in the model to assess potential adoption and impact.

The model results represent the long-term position in the adoption of the technologies, i.e., when farmers have full information about technologies and at peak adoption. This is likely to take time to be achieved. The model does not determine how long the adoption process takes before reaching peak adoption. The duration of adoption will depend on how the technologies are extended to farmers. In this respect, an efficient extension organization will hasten the adoption process. Nevertheless, the households that adopt the technologies and the area they adopt, in the long run, were determined in the model.

APPENDIX A
LAND DISTRIBUTION AND CHARACTERISTICS OF NATURAL REGIONS

Natural Region	Area (km^2)	% of Country	Rainfall (per annum)	Recommended Production systems
1	7,000	2	Above 1050 mm Received in all months of year Relatively low temperatures	Plantation crops Forestry Intensive livestock
2	58,600	15	750-1000 mm Rainfall confined to summer	Crops Intensive livestock production
3	72,900	19	650-800 mm Relatively high temperatures Infrequent heavy fall of rain Subject to seasonal droughts	Livestock production Fodder production Marginal production of maize, tobacco and cotton
4	147,800	38	450-650 mm Subject to frequent seasonal droughts	Livestock production Drought tolerant crops
5	104,400	27	Less than 450 mm Very erratic	Extensive cattle production

Adapted from Central Statistical Office (1998).

APPENDIX B
QUESTIONNAIRE AND DISCUSSION GUIDELINES

Survey of Soil fertility Management Practices by Smallholder Farmers in Mangwende Communal Areas: Household Questionnaire

February 2001

Name of Household: ____________________
Name of Respondent: ____________________
Relationship of respondent to head of household: ____________________
Name of Village: ____________________
Date of interview: ____________________
Name of Interviewer: ____________________

1. Fertilizer Purchases and Application

How many bags of each of the following types of fertilizers did your household buy in the following seasons?
Compound D
Ammonium Nitrate
Other types of fertilizers (specify)

Season	Number of Bags		
	Compound D	Ammonium Nitrate	Other (Specify)
00/01 (Current)			
2000			
1995			
1990			

Why is use of fertilizer by the household declining (or increasing)?________________
If the trend in fertilizer use is decreasing; how is this trend in affecting your method of managing soil fertility?

Tick	Method of managing decline in fertilizer use
	Reducing area applied to fertilizer
	Reducing the quantity applied per unit area
	Growing crops which require less fertilizer
	Leaving some land fallow
	Increasing the use of cattle manure
	Other (specify)

Where did you buy your fertilizer for each of the following seasons?
How much quantity of each type was purchased from each source?
What was the price per bag charged by each source?
What means did you use for transporting the fertilizer to the farm in each year?

Year	***Source(s)***	***Type***	***Quantity***	***Price***	***Transport Used***
00/01					
2000					
1995					
1990					

Codes:

Source: 1=Trader, 2=Salesman, 3=Coop
Transport: 1=Own ox-cart, 2=Hired oxcart, 3=Hired lorry, 4=Own lorry, 5= bus, 6= Wheelbarrow
If transport was hired in 2000/2001, what was the hire cost per bag ________
In which month(s) is fertilizer purchased? ______________________________________
Are there other major expenses (e.g. school fees) you have to meet at the time you buy fertilizer? Yes/No. ________
If yes, what are the expenses? ___________________________________

Is there any type fertilizer that you did not use in 2000/2001 season, but was used before. Yes/No.
What was/were the reason(s) for not using fertilizer this season?__________________

Did the non-use of any type of fertilizer in 2001 cause any change in your farming practices? Yes/No. ____________

If yes, what were the changes? ____

If chemical fertilizers were not being used, would some have been bought if fertilizer were packaged in smaller packs than 50 kg bags? Yes/No

Cattle manure

Did you use cattle manure on your farm in the last three years? Yes/No __________
If yes, what crops were planted on the land that received manure?
What area did you cover each year?
How much manure did you apply in each of the last three years?

Year	Crop	Area	Amount	Unit
98/99				
1997/98				
1996/97				

After applying manure, what rotation of crops do you follow?
What level of other fertilizers do you apply on crops in the rotation sequence?

Rotational Sequence	Crop	Fertilizer rate applied
1st		
2nd		
3rd		

If manure are not used, is it available on the farm? Yes/No
If yes, what are the reasons for not using manure? ___________________

Other sources of soil fertility

What other sources of soil fertility do you use in your fields?______________________
When did you first use this technique? ____
What size of the field is managed this way? ____________________________________

2. Method(s) of Preparing Land

What method(s) of preparing land do you use?
What crops are planted on land prepared by each method?
What area did each crop occupy in 2000/2001?

Method of land preparation	Crops planted	Area under each crop

3. Method(s) of planting

What method(s) of planting does the household use for each crop, by planting?

Crop	Planting	Date of planting
Maize Groundnuts Sunflower Cotton Other: *Specify*		

4. Method(s) of Fertilizer Application

If Compound D was purchased in the 2000/01 season,
In what crops was Compound D applied?
At what stage of each crop's development is Compound D applied to each crop?
Describe the method used for applying Compound D to each crop.
How much Compound D fertilizer was applied to each crop?

On how much area was the Compound D fertilizer applied?

Crop	Time of application	Method of application	Amount applied	Area applied

If Ammonium Nitrate was purchased in the 2000/01 season,

In what crops was Ammonium Nitrate applied?

At what stage of each crop's development is Ammonium Nitrate applied to each crop?

Describe the method used for applying Ammonium Nitrate to each crop.

How much Ammonium Nitrate fertilizer was applied to each crop?

On how much area was the Ammonium Nitrate fertilizer applied?

Crop	Time of application	Method of application	Amount applied	Area applied

5. Method(s) of Weeding

What are the methods used for weeding each crop, by planting?
At what stage are crops weeded?

Crop	Method	At what stage do you weed
	First Weeding	
	Second Weeding	

6. Cropping Pattern

What crops did you have in your fields last season?
What was the area under each crop planting?
How much area received fertilizer?
How much area received other sources of soil fertility, e.g., manure?
How much area received a mixture of fertilizer and other sources of fertility.
Is the crop intercropped with another crop, e.g., pumpkins, beans, sunflower, cowpea, groundnuts.

Crop/ Intercrop	Minor intercrop	Planting	Area planted	Area fertilized	Area with Manure	Area with mixed: Fertilizer + Manure
Maize						
Groundnuts						
Sunflower						
Cotton						
Finger-millet						

Field Beans						
Other						

7. Fallow Land

How much land did you leave fallow?
What is the soil-type of the area that was fallow?
Why did you leave the land fallow?

Season	Area	Soil-type(s)	Reason(s)
2000/01 2000 1995 1990			

8. Garden

Do you have a garden? Yes/No. _______________
If yes, what area was planted to each crop in the garden?
How much of this area had chemical fertilizer applied?
How much of this area was fertilized with a mixture of fertilizer and manure as basal fertilizer?
What quantity of fertilizer was used on each crop?

Crop planted	Total Area under crop in garden	Area with Fertilizer	Amount (kg)	Area with other	Area with mixed
Maize					
Groundnuts					
Sunflower					
Cotton					
Finger-millet					
Field Beans					
Other: *Specify*					

When is maize planted in the garden? ____
How many weeks before or after planting maize were the other crops planted in the garden?

CROP	WEEKS BEFORE/AFTER MAIZE

9. Income from non-crop activities

Did any member of your household do the following off-farm activities?
When were the off-farm activities conducted?
How much labor is required during the activity?
What financial expenses are incurred during the activity?

Activity	Y/N	When conducted	Labor required (State units)	Financial Expenses
Beer brewing House construction Selling firewood Herding livestock Brick making Vending Hire out labor Other: *Specify*				

What are the current sources of cash (on-farm or off-farm) for members of the household?
How much did the household get from each source in 1999/2000, 1998/99?
During which months was the cash income received?

Name of family member	Source of Income	Amount obtained from source		Month(s) when cash is available	Days or hours spent
		Year 2000	Previous year		

Notes: For amount, might have to rely on ranges since farmers might not remember exact figures.

10. Remittances

Did the household receive any income from relatives not resident on the farm in the following years?
2000 Yes/No
1999 Yes/No
1995 Yes/No
1990 Yes/No

Who provided remittances in 2000?
How much did each provider remit to the household?
During which month(s) are remittances received?

Name	Amount remitted	Month(s)

Did you receive any fertilizer for free from your relative or other organization? Yes/No.
If yes, 1. Who supplied the credit ?
2. What type of fertilizer was it?
3. How much of each type did you receive?

Source of fertilizer	Type	Quantity (with Units)

11. Household Composition

List the names, ages and gender of the members of this household.
What is the highest education attained by each member?
Were these members present in 1995 (Yes/No)?
Were these members present in 1990?
Do the household members work: 1-fulltime, 2-part time; or 3-do not work on the farm?
What is the relationship of each member with the head of the household?

Name	Age	Sex	Work	Years of Education	Present in 1995	Present in 1990	Relation to Head of Household
Who was in the household in 1995 but is no longer in the household?							
						//////////	
Who was in the household in 1990 but is no longer in the household?							
					///////////		

Where does the head of household normally reside? *At the farm / Away from the farm*

For each person in the household working part time on the farm the year, what time of the year does he/she work on the farm e.g. school holidays, weekends and public holidays?

Name of household member	Time working

12. Livestock and Draft Power

How many cattle does the household own? _____
How many of these are used for draft power? _____
Do you use draft power other than your own? Yes/No ______
If yes, how do you get draft power?

1. Hire at a charge ____
2. Borrow from neighbors ____
3. Share with neighbors ____

If draft power is hired, how much do you pay per acre? ___________
Who herds your cattle 1. *Adult male;* 2. *Adult male;* 3. *Children;* 4. *Worker*

13. Selling of Crops

If crops were sold in 2000, what crops were sold?
What quantity was sold and to whom? What price was received?
If more than one channel was used, give the quantity sold to each channel and the price obtained.
When did you sell to each outlet?
What means of transport was used for getting the produce to each market.
Was transport hired? Yes/No.
If transport was hired, what was the cost per bag ________.

Crop	Marketing Channel and Price	Quantity Sold	When crop was sold	Transport used	Cost of transport per bag

For food crops:
How much of each crop was stored for home consumption?

Crop	Quantity Stored

How much land do you plant to make sure you have enough to meet your consumption requirements for each crop? ____________________________________
Give the fertility that would be necessary to obtain this requirement: ________________
Did your household run out of maize in any of the last five years? Yes/No
If yes, in which year(s) did you run out? ______________
During which months did you run out of your own food?

Year	Month

In those years when you had a shortage, what means did the household use to survive? ______________
If the food was purchased, what was the source of the money used? _________________

14. Extension

Are you a member of any club or group? (Not political party) Yes/No _______
If yes, list the club names?
What activities does each group do?

Name of club	Main activities undertaken by the club

How often do you have contact with extension personnel (as a group or individually)? __
Is the frequency of your contact with extension personnel adequate? Yes/No. _______
If not, how frequently would you like to meet extension personnel? ________________

15. Credit

Did any member of the household get credit for farming activities in any of the following years?
If credit was obtained, what was its source(s)?
What was the value of the credit?
What was the credit used for?
Did you repay the credit at the end of the season?

Year	Source(s) of Credit	Value of Credit	Use (For fertilizer give amounts and types)	Was Credit Repaid
2000 1999 1995 1990				

In any of the years, was more credit needed but was denied or not available? Year(s) ___
If credit was denied, give the reasons. ___
If credit was not used in any one of the four seasons, did any member of the family ever use credit? Yes/No
If yes, what was the last time credit was used? ___
Why is it no longer used? ___
If credit is never used, what are the reasons for not using credit? ___

16. Size of the Farm

What major soil types do you have on your farm?
How many acres of your farm are under each soil type?

Major soil-type	Area under each type

17. Attitude about new technologies

Are you aware of any of the following methods of improving soil fertility?

- Improved fallows using nitrogen fixing trees Yes/No
- Green manuring Yes/No
- Soybeans Yes/No
- Leaf litter Yes/No
- Anthill soil Yes/No
- Rotation Yes/No
- Winter plowing Yes/No
- Fallowing Yes/No
- Other Yes/No

If any of the methods are known, is the household using any of them on the farm. Yes/No.

If yes, which method(s) is the household using?
What area is currently under each method?
In future, are you going to increase or decrease the area under each method?
Why?

Method used	Area under method	Increase/Decrease	Reason

If not using any of the methods, why are they not being used? ___

Are they going to be used in future? ______________________________

Have you planted trees in your field to improve soil fertility? Yes/No. ______
If yes, which trees and how many of each? ______________________
Where did you get the seedlings? ______________________
Why did you not plant more than you have? ______________________

Do you have a good source of leaf litter? Yes/No. _______
What is the dominant tree species supplying the leaf litter? ______________________
Do you have the labor for collecting, transporting and applying the leaf litter? Yes/No
Have you left any naturally growing trees in your field to improve soil fertility? Yes/No.
If yes, (a) which trees?
(b) how many?

Tree	Number of trees

Did you leave other trees in the field for other reasons? Yes/No
If yes, which ones? ________________

17. Green Manuring

Which of the following crops do you grow on your farm?
1. Pigeon peas 2. Mucuna (Velvet Beans) 3. Cowpeas
4. Soyabeans 5. Field beans 6. Groundnuts

For each crop give the main reasons for growing them?

Crop grown	Reasons		
	1	2	3

Reason code: A. To eat B. To sell C. To improve the soil

Which crops would you consider incorporating to improve the soil fertility? ________
What crop(s) would you plant on the plot on which the legume crop(s) has/have been incorporated. ____________________________

GUIDELINES FO GROUP INTERVIEWS

(The questions listed here serve as guidelines for discussions with groups of farmers.)

1. List crops grown in the area
2. List main soil types on which farming is conducted in the area.

Household types

Define the broad household types found in the area.
Demographic Characteristics of an average household in each type

<u>Membership</u>	<u>Work status</u>
Adult males	e.g., Working on farm
Adult females	Not Working on Farm/
Children	Working part-time

3. Methods of preparing land used by each type of household.
4. How many of man-hours needed for plowing one acre of land in each soil type using each of the identified methods.

Amount of labor required for preparing land.

Method of land preparation	Labor required
Winter plough + Plowing . Winter plough . Plowing	
Winter plough + ridging with plow . Ridging	
Plowing after rains	
Using hand hoes	

What are the different methods of planting each crop? Indicate the methods that are conducted by males or females. How many man-hours are needed for planting an acre?

Crop	Method	Gender	Time Taken
e.g., Maize	*e.g., Opening Furrows*	*M, F or I (Any Sex)*	
	Dropping and Covering Seed		

How many times is maize weeded?
What are the methods used for weeding? How many man-hours are needed to weed an acre?

- <u>First Weeding</u>

<u>Crop</u>	<u>Method</u>	<u>Time Taken to weed an acre</u>
Maize	a. *Ox-Cultivator*	________
	b. *Hand hoe Weeding*	________
	Hand hoe weeding alone	________

- Second Weeding

Crop an acre	Method	Time Taken to weed
Maize	e.g., *Ox-drawn Cultivator and Hand-hoe weeding*	___________
	Hand Hoe weeding	___________
	Ox-Drawn Plough and Hand hoe weeding	___________

Fertilizer and Manure Use

What methods are used for applying

- Basal fertilizer
- Top dressing

How much time does it take to apply basal fertilizer per acre using each method?
How much time does it take to apply top dressing per acre using each method?

Crop	Basal	Top Dressing
Maize, groundnuts, etc.	*Opening Holes and dropping fertilizer*	*Placing fertilizer without covering*
	Cattle manure: Digging an putting *Transporting, Spreading*	*Making hole, Placing and Covering*

On average, how much fertilizer is applied per acre for each crop?

Basal Fertilizer			
	Soil type		
	Sandy loam	Red	Black
Maize			
Groundnuts etc			
Top Dressing (AN) in Field without Manure			
Maize			
Groundnuts etc			
Top Dressing (AN) in Field with Manure			
Maize			
Groundnuts etc			

Expected Yield for all crops

Soil type	Fertilizer Level	Time of Planting	
		Early	Late
e.g., *Sandy loam*	Low		
	High		
Red, Black	Manure and Fertilizer		

Estimated man-hours required for harvesting a tonne (or some other unit of measuring weight) of each crop by mature person

Crop
Maize: Cutting and stacking ___________
Dehusking ___________
Transporting ___________
Processing: Shelling ___________
Packing ___________

Groundnuts: Digging ___________
Plucking ___________
Packing ___________

Estimate average yields over the last 5 years in each soil type.

Maize	Sandy Loam	Red	Black
2000/01			
1999/00			
1998/99			
1997/98			
1996/97			

Repeat for all crops

Timing of Operations
Maize Weeks after emergence
First Weeding ___________
Second Weeding ___________
Third Weeding ___________

Basal Fertilizer application ___________
Top Dressing application ___________
(*Repeat for all crops*)

Subsistence requirements
How much maize is consumed green in an average family (in each type) ___________
How much of each crop does the household keep for own consumption ___________

Social Responsibilities, Days per Month or Week
Meetings, Funerals, Church etc Males Females

How many males are involved?
How many females are involved?

Working Implements
Ox-drawn Plough ___________
Ox-drawn Cultivator ___________
Ox-drawn cart ___________

Garden Activities

During which months of the year do people work in Gardens?
 Vegetables
 Field Crops - What crops are planted
How many days/week for vegetables by type of household by gender?
How many days per week for field crops by type of household by gender?

Livestock and draft power ownership of each type of household.
During which months are cattle herded in the area?

APPENDIX C
LABOR REQUIREMENTS FOR CROP PRODUCTION

Crop	Operation	Days per Hectare
All crops	Land preparation with ox-drawn plow	20
Maize	Planting	
	Using ridges[a]	5
	Hand hoe planting/Wire	17
Groundnuts	Planting	
	Hand hoe planting	19
	Making ridges then harrowing	11
	Cover seed with feet	15
	Planting in lines marked with a wire	26
Finger millet (Including rice, Sorghum)	Planting	
	Ridge	1
	Broadcasting	1
	Dropping and covering with foot	1
Sweet potatoes	Planting	
	Planting on raise beds	10
	Planting on ridges	14
	On flat bed	15
Maize	Weeding	
	Cultivator	3
	Hand weeding after cultivation	16
	Hand weeding without cultivation	27
	Using plough	5
	Hand weeding after hand hoe planting	64
Groundnuts	Weeding	
	Using cultivator	4
	Hand weeding after cultivation	24
	Hand hoes alone	50
Sunflower	Weeding	
	Cultivating	7
Sweet potatoes	Weeding	
	Hand hoe weeding	55
	Cultivator making ridges	1
	Hand weeding on Ridges after Cultivator	10

Crop	Operation	Days per Hectare
Maize	Fertilizer Application	
	Basal fertilizer:	
	Dropping after germination (no holes)	4
	Covering with cultivator	3
	Digging holes and placing fertilizer	3
	Dropping Top dressing per station	2
Groundnuts	Harvesting	
	Pulling, Plucking, Transporting, Packing	50
Maize	Cutting, Stacking, De-husking, Transporting	73
	Processing	35
Finger millet	Cutting, Threshing, Packing	50
Sunflower and Soybeans	Cutting, Threshing, Packing	35
Cotton	Picking and Packing	47
	Cutting Stalks	5

[a] Planting in plow furrows requires an additional person for plowing

APPENDIX D
STRUCTURE OF THE LINEAR PROGRAMMING MODEL

The variables names for crop activities and non-farming activities used in the model are specified in Tables D-1 and D-2, respectively.

Table D-1. Description of the crop variables used in the model

Activity			Detailed activity			
Number	Name	Code	Transfers	Subsistence	Consumption	Sold
1	Maize	MZ	MZt	MZs	MZc	MZm
2	Garden maize	GMZ	n.a.#	n.a.	n.a.	n.a.
3	Groundnuts	GN	GNt	GNs	GNc	GNm
4	Bambara nuts	BN	BNt	BNs	BNc	n.a.
5	Finger millet	FM	FMt	FMs	FMc	n.a.
6	Sunflower	SF	n.a.	n.a.	n.a.	SFm
7	Cotton	CT	n.a.	n.a.	n.a.	CTm
8	Sweet potatoes	SP	SPt	SPs	SPc	n.a.
18	Soybeans	SB	n.a.	n.a.	n.a.	SBm

n.a.# = Not applicable

Table D-2. Description of the non-farming variables used in the model

Activity Number	Activity Name	Variable	Detailed activity		
			Males	Females	Maximum level
9	Horticulture	Ho	MHot	FHo	mHo
10	Labor hired out	Lo	MLo	FLo	mLo
11	Labor hired in	Li	MLi	FLi	mLi
12	Vending	V	n.a.[a]	V	mV
13	Poultry	Pl	MPl	FPl	mPl
14	Beer	Br	n.a.	Br	mBr
15	Construction	Cn	Cn	n.a.	mCn
16	Peanut Butter	PB	n.a.	PB	mPB
17	Bricks	BK	MBK	FBK	mBK
19	Purchase Maize	MZP	MMZP	n.a.	n.a.
20	Cattle manure	Man	n.a.	Man	n.a.

n.a.[a] = Not applicable

Notation of parameters for activities in the model:

A^i = Gross revenue for unit activity i;
B^i = Male labor required by unit of activity i;
C^i = Female labor required by unit of activity i;
D^i = Cash expenditure required for unit activity i;
E^i = Yield per hectare for crop i;
F = Maize grain required for producing one day's equivalent of beer;
G = Groundnut required for producing one day's equivalent of peanut butter;

The superscripts, i, are the activity numbers as given in Table D-1 and D-2. The subscripts in the model are as shown in Table D-3.

Table D-3. Notation of subscripts used in the model.

Notation	Description	Valid numbers
c	Quarters of the year	1 = 1st quarter (October – December)
		2 = 2nd quarter (January – March)
		3 = 3rd quarter (April – June)
		4 = 4th quarter (July – September)
k	Maize chemical fertilizer levels (no manure)	1 = 0 Compound D +15 N kg/ha Ammonium Nitrate (AN)
		2 = 20 N kg ha^{-1} Compound D + 90 N kg ha^{-1} AN
		3 = No fertilizers
n	Chemical fertilizers levels on field with cattle manure	1 = 16 N kg ha^{-1} Compound D
		2 = 48 N kg ha^{-1} Compound D
		3 = 80 N kg ha^{-1} Compound D
		4 = 0 fertilizer
l	Chemical fertilizer levels in cotton	1 = 50 kg ha^{-1} Compound D + 50 kg ha^{-1} AN
		2 = 50 kg ha^{-1} Compound D + 50 kg ha^{-1} AN
		3 = 50 kg ha^{-1} Compound D + 50 kg ha^{-1} AN
m	Time of planting	1 = Planting in the first quarter
		2 = Planting in the second quarter

Notation of resource transfer activities in the model:

($X_{c.(c+1)}$) resource X transferred from quarter c to the following quarter c+1.

($X_{(c-1).c}$) resource X transferred from previous quarter c-1 to the current quarter c.

Model objective function

The model maximizes the sum of income, Y_{ct}, from each quarter, c, in each year, t, of the five years that it spans.

Maximize: $\sum_t \sum_c Y_{ct}$ for all c and t.

A five-year LP model was constructed and run for all sample households. The constraints for one year, repeated to the other years, are presented in this appendix.

Land constraint

The household allocates its land to different crops. Crops grown in the systems are listed in Table A.1. All crops, except groundnuts, can be planted early or late. Early planted crops are planted in the first quarter. Late planted crops are planted in the second quarter. Groundnuts are only planted early, in the first quarter. In addition, manure can be applied to the land. Maize is planted on the land with manure. Land constraint stipulates that the area under crops in a given year cannot exceed the arable land that the household possesses.

Equation 1: $\sum_m\sum_k(MZ)_{km} + \sum_m\sum_n(MZ)_{nm} + (GN) + \sum_m(BN)_m + \sum_m(FM)_m$

$$+ \sum_m(SF)_m + \sum_m(SB)_m + \sum_l(CT)_l + \sum_m(SP)_m \leq L$$

for all k, l, m and n.

Male labor in the first and second quarter

Activities are conducted at different times of the year as discussed in Chapter 4, so the opportunity cost of labor also varies within the year. Some households differentiate labor by gender, while others do not. In food deficit households, labor might also be expended in working for food. Working for food can take place throughout the year, depending on when the household seeks to bridge up the food deficit.
The differentiation and timing of labor use are reflected in equations 2 to 5.

Equation 2. $\sum_m\sum_k(MZ)_{km}B^1{}_{kmc} + \sum_m\sum_n(MZ)_{nm}B^1{}_{nmc} + \sum_k(GMZ)_kB^2{}_{kc} + (MMZP)_cB^{19}{}_c$

$$+(GN)B^3{}_c + \sum_m(BN)_mB^4{}_{mc} + \sum_m(FM)_mB^5{}_{mc} + \sum_m(SF)_mB^6{}_{mc} + \sum_l(CT)_lB^7{}_{lc}$$

$$+\sum_m(SP)_mB^8{}_{mc} + (Lo)_c - (Li)_c + (MPl)_c \leq (Mlab)_c$$

Female labor in the first and second quarters

Equation 3. $\sum_m\sum_k(MZ)_{km}C^1{}_{kmc} + \sum_m\sum_n(MZ)_{nm}C^1{}_{nmc} + \sum_k(GMZ)_kC^2{}_{kc} + (FMZP)_bC^{19}{}_c$

$$+(GN)C^3{}_c + \sum_m(BN)_mC^4{}_{mc} + \sum_m(FM)_mC^5{}_{mc} + \sum_m(SF)_mC^6{}_{mc} + \sum_l(CT)_lC^7{}_{lc}$$

$$+\sum_m(SP)_mC^8{}_{mc} + (Lo)_c - (Li)_c + (MPl)_c + V_c + (Br)_c \leq (Flab)_c$$

Male labor in the third and fourth quarter

Equation 4. $\sum_m\sum_k(MZ)_{km}B^1{}_{kmc} + \sum_m\sum_n(MZ)_{nm}B^1{}_{nmc} + (MMZP)_cB^{19}{}_c + \sum_k(GMZ)_mB^2{}_{mc}$

$+ (GN)B^3{}_{mc} + \sum_m(BN)_mB^4{}_{mc} + \sum_m(FM)_mB^5{}_{mc} + \sum_l(SF)_mB^6{}_{mc} + \sum_m(CT)_lB^7{}_{lc}$

$+ \sum_m(SP)_mB^8{}_{mc} + (Con)_cB^{20}{}_c + (MPl)_c + (MHo)_cB^9{}_c + (MBK)_c \leq (Mlab)_c$

Female labor in the third and fourth quarters

Equation 5. $\sum_m\sum_k(MZ)_{km}C^1{}_{kmc} + \sum_m\sum_n(MZ)_{nm}C^1{}_{nmc} + (FMZP)_cC^{19}{}_c + \sum_k(GMZ)_kC^2{}_{kc}$

$+ (GN)C^3{}_c + \sum_m(BN)_mC^4{}_{mc} + \sum_m(FM)_mC^5{}_{mc} + \sum_m(SF)_mC^6{}_{mc} + \sum_l(CT)_lC^7{}_{lc}$

$+ \sum_m(SP)_mC^8{}_{mc} + (Lo)_c - (Li)_c + (FPl)_c + V_c + (Br)_c$

$+ (FHo)C^9{}_c + (FBK)_c + (PB)_c \leq (Flab)_c$

Cash at the beginning of quarter c $(CSB)_c$.

This variable is the cash used for farming from the beginning to the end of the season obtained from sources such as sales of the previous year's crop, remittances, and non-farming activities. Use of credit has been declining over the years. Credit was used by 6% and 26% of the sample farmers in 2000 and 1990, respectively. In 2000, credit was only available for groundnut inputs.

Households start the year or quarter with a stock of cash. This is cash carried over from the previous year or quarter. Exogenous cash is injected into the system through remittances from members who are employed and stay away from home. The household also needs to pay for the expenditure they incur during that quarter.

At the end of the season, any surplus is transferred to the income at the end of the quarter. Expenditure in each crop depends on the stage of development of the crop. For example, early-planted maize is top dressed at a different time from that of the late-planted crop. Crops under different levels of management also require different financial resources, e.g., maize produced using chemical fertilizer alone requires expenditure for basal fertilizer at planting. This is not required in maize produced using a combination of cattle manure and chemical fertilizer.

Equation 6. $\sum_m\sum_k(MZ)_{km}D^1{}_{kmc} + \sum_m\sum_n(MZ)_{nm}D^1{}_{nmc} + \sum_k(GMZt)_kD^{21}{}_{kc} + \sum_n(GMZt)_kD^{21}{}_{kc}$

$+ \sum_k(GMZt\text{-}1)_kD^{22}{}_{kc} + (GN)D^3{}_c + \sum_n(GMZt\text{-}1)_kD^{22}{}_{kc} + \sum_m\sum_n(MZ2)_{nm}D^1{}_{nmc}$

$+ \sum_m(BN)_mD^4{}_{mc} + \sum_m(FM)_mD^5{}_{mc} + \sum_m(SF)_mD^6{}_{mc} + \sum_l(CT)_lD^7{}_{lc} + V_cD^{12}{}_c$

$+ (CSt_{c.(c+1)}) - (CSt_{(c-1).c}) - (Lo)_cD^{10}{}_c + (Li)_cD^{11}{}_c + (MPl + FPl)_cD^{13}{}_c$
$+ (Br)_cD^{14}{}_c \leq (CSB)_c$ for $c = 1,2$ and $m = 1,2$

Equation 7. **Cash at the beginning quarter**

$$\sum_{m}\sum_{k}(MZ)_{km}D^{1}_{kmc} + \sum_{m}\sum_{n}(MZ)_{nm}D^{1}_{nmc} + \sum_{k}(GMZt)_{k}D^{21}_{kc} + \sum_{n}(GMZt)_{k}D^{21}_{kc}$$
$$+\sum_{k}(GMZt\text{-}1)_{k}D^{22}_{kc} + \sum_{n}(GMZt\text{-}1)_{k}D^{22}_{kc} + \sum_{m}\sum_{n}(MZ2)_{nm}D^{1}_{nmc} + (GN)D^{3}_{c}$$
$$+\sum_{M}(BN)_{m}D^{4}_{mc} + \sum_{M}(FM)_{m}D^{5}_{mc} + \sum_{M}(SF)_{m}D^{6}_{mc} + \sum_{L}(CT)_{l}D^{7}_{lc} + (CSt_{c.(c+1)})$$
$$-(CSt_{(c-1).c}) - (Lo)_{c}D^{10}_{c} + (Li)_{c}D^{11}_{c} + (MPl + FPl)_{c}D^{13}_{c}$$
$$+(V)_{c}D^{12}_{c} + (Br)_{c}D^{14}_{c} + (MHo + FHo)_{c}D^{9}_{c} + (Con)_{c}D^{15}_{c} + (PB)_{c}D^{16}_{c}$$
$$+(MBK + FBK)_{c}D^{17}_{c} \leq (CSB)_{c} \quad \text{for } c = 3,4 \text{ and } m = 1,2$$

Cash income. The model maximizes the discretionary income at the end of five years, by adding up the income at the end of each year. Some of the income is transferred from the previous quarter, c-1, after taking account of the expenditure in quarter c. The sources that contribute to income vary in each quarter. Some non-farming activities, such as poultry production and beer brewing, bring in cash each quarter income of the year. Other activities like selling crops only bring income in one quarter of the year. Some income is transferred to the next quarter to meet the future expenses.

Equation 8. $-(Br)_{c}A^{14}_{c} - (Pl)_{c}A^{13}_{c} - V_{c}A^{12}_{c} - (CSt_{1\text{-}1})_{c} + (CSt_{1\text{-}2})_{c} + Y_{c} = 0$
for $c = 1$

Equation 9. $-(GNm)_{c}A^{3}_{c} - (SF)_{c}A^{6}_{c} - V_{c}A^{12}_{c} - (Pl)_{c}A^{13}_{c} - (Br)_{c}A^{14}_{c} - (CSt_{2\text{-}2})_{c} + (CSt_{2\text{-}3})_{c} + Y_{c} = 0 \quad \text{For } c = 2$

Equation 10. $-(MZm)_{c}A^{1}_{c} - (SF)_{c}A^{6}_{c} - (SBm)_{c}A^{18}_{c} - (CTm)_{c}A^{7}_{c} - (CSt_{c.c})_{c} + (CSt_{c.(c+1)})_{c} - V_{c}A^{12}_{c} - (Pl)_{c}A^{13}_{c} - (Br)_{c}A^{14}_{c} - (BK)_{c}A^{17}_{c} - (PB)_{c}A^{16}_{c} - Cn)_{c}A^{15}_{c} - (Ho)_{c}A^{9}_{c} + Y_{c} = 0 \quad \text{for } c = 3.$

Equation 11. $-(Ho)_{c}A^{9}_{c} - (Pl)_{c}A^{13}_{c} - (Br)_{c}A^{14}_{c} - (PB)A^{16} - (BK)_{c}A^{17}_{c} - V_{c}A^{12}_{c} - (Cn)_{c}A^{15}_{c} - (CSt_{c.c})_{c} + (CSt_{(c-1).c}) + Y_{c} = 0 \quad \text{for } c = 4.$

Once-in-a-year constraints

Garden Area Accounting. The area planted to maize in the garden cannot exceed the size of the garden. In the garden, cattle manure or chemical fertilizers can be used solely, or in combination as with field maize.

Equation 12. $\sum_{k}(GMZ)_{kt} + \sum_{n}(GMZ)_{nt} \leq (Gdn)$

Garden maize is planted in the third quarter. Therefore, its cycle spans two years, i.e., planted in the third quarter of year t and harvested in the second quarter of the following year, t+1. Garden area planted in year t, is transferred into the next season. Similarly, garden area planted in year, t-1 i.e., GMZ(t-1) is only harvested in year t. In equations 13 to 14, area of maize planted in the garden in year t, i.e., GMZ(t) is transferred into the following year, t+1. Similarly, in equations 15-16, garden area

planted in the preceding year (t-1) is transferred into current year (t). In the equations, land with manure is distinguished from land without manure.

Equation 13. $(GMZ(t))_{kt} - (GMZ(t))_{k(t+1)} = 0$

Equation 14. $(GMZ(t))_{nt} - (GMZ(t))_{n(t+1)} = 0$

Equation 15. $(GMZ(t\text{-}1))_{k(t-1)} - (GMZ(t\text{-}1))_{kt} = 0$

Equation 16. $(GMZ(t\text{-}1))_{n(t-1)} - (GMZ(t\text{-}1))_{nt} = 0$

Manure area planted to maize in year t is replanted to maize in the following year, t+1. Equation 17 ensures that the area under manure in year t-1 is the same as the area planted to the same plots in the second season.

Equation 17. $\sum_n (MZ)_{n(t-1)} - \sum_n (MZ2)_{nt} = 0$

The area applied with manure in the last year *t*-1, is planted to field maize or garden maize in year t.

Equation 18. $\sum_n (MZ)_{nt} - \sum_n (GMZ)_{nt} + (Man)_{t-1} = 0$ for t = 1,and n = 1,..,4

The area under maize in season *t* equals the area planted to maize on residual manure in the following year, i.e.,(*t*+1).

Equation 20. $\sum_n (MZ)_{nt} - \sum_n (MZ2)_{n(t-1)} = 0$ for t = 1,n = 1,..,4

Generating manure area. Manure area generated in year *t* equals all the manure area transferred to the following year, i.e., (*t*+1).

Equation 21. $(Man)_t - (Man)_{t+1} = 0$ for t = 1

Crop accounting. Maize transferred from years t-1 should be equal to maize for consumption and maize transferred to the next quarter. Maize is also brought in from harvests from garden plots in the second quarter and from the field crop in the third quarter. The same applies to GN and BN only that they are not produced in gardens. Maize is used is an input in beer production while groundnuts are used in making peanut butter during the third and fourth quarters. Cash crops like sunflower and cotton are produced and sold on the market without transferring them from one quarter to another.

Equation 22. Maize in 1st quarter

$$(MZc)_c + (MZt_{c.c})_c + 0.9(MZt_{(t-1).t})_c + (Br)_c F^{14}{}_c = 0 \text{ for } c = 1$$

Equation 23. Groundnuts in 1st quarter

$$(GNc)_c + (Pb)_c G^{16}{}_c + (GNt_{c.(c+1)})_c - (GNt_{(c-1).c})_c = 0 \text{ for } c = 1$$

Equation 24. Bambara nuts in 1st quarter

$$(BNc)_c - 0.96(BNt_{(c-1).c})_c + (BNt_{c.(c+1)})_c = 0 \quad \text{for } c = 1$$

Equation 24. Maize in 2nd quarter

$$-\sum_k (GMZ)_{kc}E^1{}_c - \sum_n (GMZ)_{nc}E^1{}_c + (Br)_cF^{14}{}_c + (MZc)_c - 0.9(MZt_{(c-1).c})_c$$

$$+(MZt_{(c-1)-c})_c = 0 \quad \text{for } c = 2$$

Equation 26. Groundnuts in 2nd quarter

$$-(GN)_cE^3{}_c - 0.96(GNt_{(c-1).c})_c + (GNc)_c + (PB)_c + (GN_{(c.(c+1)})_c$$
$$+(GNm)_c = 0 \text{ for } c = 2$$

Equation 27. Sweet potatoes in 2nd quarter

$$-(SP)_cE^8{}_c + (SPc)_c + (SPt_{c.(c+1)}) = 0 \text{ for } c = 2$$

Equation 28. Bambara nuts in 2nd quarter

$$-(BN)_cE^4{}_c - 0.96(BNt_{(c-1).c})_c + (BNc)_c + (BNt_{c.(C+1)})_c = 0$$
$$\text{for } c = 2$$

Equation 29. Sunflower in 2nd quarter

$$-(SF)_cE^6{}_c + (SFm)_c = 0 \text{ for } c = 2$$

Equation 30. Maize in 3rd quarter

$$-\sum_m\sum_k (MZ)_{kmc}E^1{}_{kmc} - \sum_m\sum_n (MZ1)_{nmc}E^1{}_{nmc} + (MZm)_c - 0.9\sum_m\sum_n (MMZ2)_{nmc}E^1{}_{nmc}$$

$$-0.9(MZt_{(c-1).c})_c + MZc)_c + MZt_{c.(c+1)}) + (Br)_cF^{14}{}_c = 0$$
$$\text{for } c = 3,\ m = 1,2\ k = 1,2,3 \text{ and } n = 1,..,4.$$

Equation 31. Groundnuts in 3rd quarter

$$-0.96(GNt_{(c-1).c})_c + (GNc)_c - (GNt_{c.(c+1)})_c + (PB2)_cG^3{}_c = 0 \text{ for } c = 3.$$
$$-(BN)_cE^4{}_c - 0.96(BNt_{(c-1).c})_c + (BNc)_c + (BNt_{c.(C+1)})_c$$
$$+(BNt_{c.(c+2)})_c = 0 \text{ for } c = 3.$$

Equation 32. Finger millet in 3rd quarter

$$-\sum_m (FM)_{mc}E^5{}_{mc} + (FMc)_c + (FMt_{c.(c+1)})_c + (FMt_{c.(c+4)})_c = 0 \text{ for } c = 3.$$

Equation 33. Sweet potatoes in 3rd quarter

$$-(SP)_cE^8{}_c + (SPc)_c + (SPt_{c.(c+1)}) - 0.96(SPt_{(c-1).c}) = 0 \text{ for } c = 3.$$

Equation 34. Cotton in 3rd quarter

$$-\sum_l (CT)_{lc}E^7{}_c + (CTm)_c = 0 \text{ for } c = 3.$$

Equation 35. Sunflower in 3rd quarter

$$-(SF)_cE^6{}_c + (SFm)_c = 0 \quad \text{for } c = 3.$$

Equation 36. Soyabeans in 3rd quarter

$$-\sum_{m}(SB)_{mc}E^{18}_{mc} + (SBm)_c = 0 \text{ for } c = 3.$$

Equation 37. Maize in 4th quarter

$$-0.9(MZt_{(c-1).c})_c + (MZc)_c + (MZt_{c.(c+1)})_c + (Br)_c F^{14}_c = 0 \text{ for } c = 4$$

Equation 38. Groundnuts in 4th quarter

$$-0.96(GNt_{(c-1).c})_c + (GNc)_c + -(GNt_{c.(c+1)})_c + (Pbtr2)_c G^{16}_c = 0 \text{ for } c = 4$$

Maximum limits on non-farming activities

The limits on the level of non-farm activities that households could engage in were determined from survey data. Without placing limits, the model would have allowed some households to exceed the stipulated limits, which would have been unrealistic since such a scenario would result in over supply on the markets. Farmers avoid over supply. For example for beer brewing, they indicated that they took turns to ensure that the person selling in any day was guaranteed of buyers.

Equation 39. Beer

$$(Br)_c \leq (mBr)_c \text{ for } c = 3,4$$

Equation 40. House construction

$$(Con)_c \leq (mCn)_c \text{ for } c = 3,4$$

Equation 41. Molding bricks

$$(MBK)_c + (FBK)_c \leq (mBK)_c \text{ for } c = 3,4$$

Equation 42. Vending

$$V_c \leq (mV)_c \text{ for } c = 1,2,3,4$$

Equation 43. Market gardening

$$(MHo)_c + (FHo)_c \leq (mMot)_c \text{ for } c = 1,2.$$

Maximum activity levels

Equation 44. Labor hired out

$$(MLo)_c + (Flo)_c \leq (mLo)_c \text{ for } c = 1,2.$$

Equation 45. Poultry

$$(MPl)_c + (FPl)_c \leq (mPl)_c \text{ for } c = 1,2,3,4.$$

Equation 46. Peanut butter

$$(PB)_c \leq (mPB)_c \text{ for } c = 3,4.$$

EQUATION 47. LABOR HIRED IN

$(Mli)_c + (FLi)_c \leq (mLi)_c$ for c = 1,2.

Accounting for Non-crop activities

Equation 48. Poultry

$(MPl)_c + (FPl)_c + (Pl)_c = 0$ for c = 1,..,4.

Equation 49. Peanut butter

$(PB1)_c + (PB2)_c - (PB)_c = 0$ for c = 3,4.

Equation 50. Brick molding

$(MBK)_c + (FBK)_c - (BK)_c = 0$ for c = 3,4.

Consumption Requirements

Typically, semi-commercial smallholder farm households store some food for consumption by their membership. The quantity of the staple food crops that each household stores every season was obtained during the survey. Maize subsistence consumption requirements were expressed as a regression equation. This was to allow variations in household composition to be allowed during sensitivity analysis to be captured through the consumption regression model. Results of the consumption regression model are reported in Chapter 5.

Maize for subsistence requirements is met from maize transferred to consumption from the preceding quarter, plus maize obtained by working on other people's farms. A minimum level of subsistence requirements has to be met in each quarter.

Equation 51. Maize

$-(MZt_{c.c})_c - (MMZP)_c - (FMZP)_c \leq -(MZs)_c$ for c = 1,..,4.

Equation 52. Groundnuts

$-(GNt_{c.\,c})_c \leq -(GNs)_c$ for c = 1,..,4.

Bambara nuts are transferred directly from third quarter (c=3) hence the 0.96 to reflect losses during storage and processing.

Equation 53. Bambara nuts

$-(BNt_{c.c})_c \leq -(BNs)_c$ for c = 1,2,3.

Equation 54. Bambara nuts

$-0.96(BNt_{c.c})_c \leq (BNs)_c$ for c = 4.

Area planted to groundnuts in year t has to be less than equal to the maximum area that farmers can plant to groundnuts.

Equation 55: Groundnuts

$$(GN)_c \leq (mGN)_c \text{ for } c = 1,..,4.$$

Households owned few cattle. Therefore, a limited area could be applied to manure each year. An average area is used in the model.

Equation 57: Manure

$$(Man)_t \leq (mMan)_t \text{ For all } t$$

The income generated in quarter c of year t has to be greater than or equal to the income required to meet the cash requirements of the household in that quarter.

Equation 58: Income

$$Y_c \geq (\min Y)_c$$

APPENDIX E
MODIFICATIONS ON LINEAR PROGRAMMING MODEL

This appendix specifies the additions that were added to equations or additional equations to those in Appendix D. Where the equation numbers in Appendix D and E are the same, then the additions are placed on the left hand side of the equations.

Additional Notation

$SS_{1,t}$ = One year Sesbania sesban improved fallow planted in year t.
$CP_{1,t}$ = One year Cowpeas improved fallow planted in year t.
$PP_{1,t}$ = One year Pigeon peas improved fallow planted in year t.
$M1S_{1,t}$ = First maize crop planted after 1 year Sesbania sesban improved fallow planted in year t.
$M1C_t$ = First maize crop planted after 1 year Cowpeas planted in year t.
A^p =Pigeon pea seed price per 1000 kg
A^c =Cowpea price per 1000 kg

Table E-1. Improved fallow and green manure codes

Number of fallow years	Year of planting	Activity Number		
		Sesbania sesban	Pigeon peas	Cowpeas
1	1	21	28	35
1	2	22	29	36
1	3	23	30	37
1	4	24	31	38
2	1	25	32	n.a.[#]
2	2	26	33	n.a.
3	1	27	34	n.a.

[#]n.a. = Not applicable

ADDITIONAL EQUATIONS

Equation 1a. Area under Improved fallows

Year 1. $+(SS_{1.t})_t +(SS_{2.t})_t +(SS_{3.t})_t +(PP_{1.t})_t +(PP_{1.t})_t +(PP_{1.t})_t +(CP_t)_t$ for t = 1

Year 2. $+(SS_{2.(t-1)})_t +(SS_{3.(t-1)})_t +(SS_{1.t})_t +(SS_{2.t})_t +(PP_{2.(t-1)})_t +(PP_{3.(t-1)})_t +(PP_{1.t)})_t +(PP_{2.t})_t$
$+(CP_t)_t$ for t = 2

Year 3. $+(SS_{2.(t-1)})_t +(SS_{3.(t-2)})_t +(SS_{1.t})_t +(PP_{2.(t-1)})_t +(PP_{3.(t-2)})_t +(PP_{1.t})_t +(CP_t)_t$ for t = 3

Year 4. $+(SS_{1.t})_t +(PP_{1.t})_t +(CP_t)_t$

Equation 1b. Area under maize grown after fallow plots

Year 2. $+(M1S_{1.(t-1)})_t +(M1P_{1.(t-1)})_t +(M1C_{(t-1)})_t$ for t = 2

Year 3. $+(M1S_{2.(t-2)})_t +(M1S_{1.(t-1)})_t +(M1P_{2.(t-2)})_t +(M1P_{1.(t-1)})_t +(M1P_{(t-1)})_t$
$+(M2S_{1.(t-2)})_t +(M2P_{1.(t-2)})_t +(M2C_{(t-2)})_t$ for t = 3

Year 4. $+ (M1S_{3.(t-3)})_t + (M1S_{2.(t-2)})_t + (M1S_{1.(t-1)})_t + (M1P_{3.(t-3)})_t +(M1P_{2.(t-2)})_t$
$+ (M1P_{1.(t-1)})_t + (M1C_{(t-1)})_t + (M2S_{2.(t-3)})_t + (M2S_{1.(t-2)})_t + (M2P_{2.(t-3)})_t$
$+ (M2P_{1.(t-2)})_t + (M2C_{(t-2)})_t$ for t = 4

Year 5. $+ (M1S_{1.(t-1)})_t + (M1P_{1.(t-1)})_t + (M1C_{(t-1)})_t + (M2S_{3.(t-4)})_t + (M2S_{2.(t-3)})_t + (M2S_{1.(t-2)})_t$
$+ (M2P_{3.(t-4)})_t + (M2P_{2.(t-3)})_t + (M2P_{1.(t-2)})_t + (M2C_{(t-2)})_t$

Equation 2a. Male labor in 1st and 2nd Quarter
Male labor requirements for improved fallows

Year 1. $+ (SS_{1.t})_tB^{21}{}_c + (SS_{2.t})_tB^{22}{}_c + (SS_{3.t})_tB^{23}{}_c + (PP_{1.t})_tB^{28}{}_c + (PP_{2.t})_tB^{29}{}_c$
$+ (PP_{3.t})_tB^{30}{}_c + (CP_t)_tB^{35}{}_c$

Year 2. $+ (SS_{1.t})_tB^{24}{}_c + (SS_{2.t})_tB^{25}{}_c + (PP_{1.t})_tB^{31}{}_c + (PP_{2.t})_tB^{32}{}_c + (CP_t)_tB^{36}{}_c$

Year 3. $+ (SS_{1.t})_tB^{26}{}_c + (PP_{1.t})_tB^{33}{}_c + (CP_t)_tB^{37}{}_c$

Year 4. $+ (SS_{1.t})_tB^{27}{}_c + (PP_{1.t})_tB^{34}{}_c + (CP_t)_tB^{38}{}_t$

Equation 2b. Male labor in 1st and 2nd Quarter

Male labor requirements for fallow maize.
Additions to the left hand side of the equation in each year

Year 2. $+ (M1S_{1.(t-1)})_tB^{21}{}_c + (M1P_{1.(t-1)})_tB^{28}{}_c + (M1C_{(t-1)})_tB^{35}{}_c$

Year 3. $+ (M1S_{2.(t-2)})_tB^{22}{}_c + (M1S_{1.(t-1)})_tB^{24}{}_c + (M1P_{2.(t-2)})_tB^{29}{}_c + (M1P_{1.(t-1)})_tB^{31}{}_c$
$+ (M1P_{(t-1)})_tB^{35}{}_c + (M2S_{1.(t-2)})_tB^{21}{}_c + (M2P_{1.(t-2)})_tB^{28}{}_c + (M2C_{(t-2)})_tB^{35}{}_c$

Year 4. $+ (M1S_{3.(t-3)})_tB^{23}{}_c + (M1S_{2.(t-2)})_tB^{25}{}_c + (M1S_{1.(t-1)})_tB^{26}{}_c + (M1P_{3.(t-3)})_tB^{30}{}_c$
$+ (M1P_{2.(t-2)})_tB^{32}{}_c + (M1P_{1.(t-1)})B^{35}{}_c + (M1C_{(t-1)})_tB^{37}{}_c + (M2S_{2.(t-3)})_tB^{22}{}_c$
$+ (M2S_{1.(t-2)})_tB^{24}{}_c + (M2P_{2.(t-3)})_tB^{29}{}_c + (M2P_{1.(t-2)})_tB^{31}{}_c + (M2C_{(t-2)})_tB^{35}{}_c$

Year 5. $+ (M1S_{1.(t-1)})_tB^{27}{}_c + (M1P_{1.(t-1)})_tB^{37}{}_c + (M1C_{(t-1)})_tB^{38}{}_c + (M2S_{3.(t-4)})_tB^{23}{}_c$
$+ (M2S_{2.(t-3)})_tB^{25}{}_c + (M2S_{1.(t-4)})_tB^{26}{}_c + (M2P_{3.(t-4)})_tB^{30}{}_c + (M2P_{2.(t-3)})_tB^{32}{}_c$
$+ (M2P_{1.(t-2)})_tB^{35}{}_c + (M2C_{(t-2)})_tB^{37}{}_c$

Equation 3. Female labor in 1st and 2nd Quarter in maize following improved fallows

B in Equation 2b is replaced by C

Equation 4a. Male labor in 3rd Quarter in improved fallows
Additions to the left hand side of the equation in each year

Year 1. $+ (CP_t)_tB^{35}{}_c$ for $t = 1, c = 3$

Year 2. $+ (CP_t)_tB^{36}{}_c$ for $t = 2, c = 3$

Year 3. $+ (CP_t)_tB^{37}{}_c$ for $t = 3, c = 3$

Year 4. $+ (CP_t)_tB^{38}{}_c$ for $t = 4, c = 3$

Equation 4b. Male labor for improved fallows in 4th Quarter

Additions to the left hand side of the equation in each year

Year 1. $+ (SS_{1.t})_tB^{21}{}_c + (PP_{1.t})_tB^{28}{}_c$ for $t = 1, c = 4$

Year 2. $+ (SS_{2.(t-1)})_tB^{22}{}_c + (SS_{1.t})_tB^{24}{}_c + (PP_{2.(t-1)})_tB^{29}{}_c + PP_{1.t})_tB^{31}{}_c$
for $t = 2, c = 4$

Year 3. $+ (SS_{3.(t-2)})_tB^{23}{}_c + (SS_{2.(t-1)})_tB^{25}{}_c + (SS_{1.t})_tB^{26}{}_c + (PP_{3.(t-2)})_tB^{30}{}_c$
$+ (PP_{2.(t-1)})_tB^{32}{}_c + (PP_{1.t})_tB^{35}{}_c$ for $t = 3, c = 4$

Year 4. $+ (SS_{1.4})_tB^{27}{}_c + (PP_{1.4})_tB^{37}{}_c$ for $t = 4, c = 4$

Equation 4c. Male labor requirements for fallow maize

B in equation 2b for is replaced by B_c (for $c = 3,4$) for Third and fourth quarters

Equation 5a. Female labor in 3rd Quarter

Replace B in equation 4a (Male labor in improved fallows in 3rd quarter)

Equation 5b. Female labor for improved fallow in 4th Quarter

Replace B in equation 4b (Male labor in improved fallows in 4th quarter)

Equation 5c. Female labor requirements for fallow maize in 3rd and 4th quarters
B in equation 2b is replaced by C (for $c = 3,4$)

Cash at the beginning of the quarter, c.

Equation 6a. Improved fallow costs

Replace B in Equation 2a with D for $c = 3$

Equation 6b. Maize production costs
Replace B in Equation 2b by D for the yield of each crop for $c = 1$

Cash income.
Equation 10. Cash income in 3rd Quarter of each year:
Additions to the left hand side of the equation in each year

Replace B in Equation 4a with A

Equation 11. Modification to equation 11 only when pigeon peas area marketed
Different fallows are harvested and marketed in each year so that the modification on the equation is differ ach year.

Year 1. $(P_{1.1})A^P + (P_{2.1})A^P + (P_{3.1})A^P$
Year 2. $(P_{2.1})A^P + (P_{3.1})A^P + (P_{1.2})A^P + (P_{2.2})A^P$
Year 3. $(P_{2.2})A^P + (P_{1.2})A^P$
Year 4. $(P_{1.4})A^P$

Equation 30. Accounting for Maize in 3rd quarter
Replaced B in Equation 2b with E for the fallow maize yield.

Accounting Equations for Cowpea fallows

The fallows area in year t should be equal to the area planted to maize in year t+1.

Equation 59a. $(CP_t)_t - (M_1C_t)_{t+1} = 0$ for $t = 1,..4$

The area planted to maize after the green manure is replanted to maize in year t+2

Equation 59a. $(M_1C_{t-1})_t - (M_2C_{t-1})_{t+1} = 0$ for $t = 1,2,3$

(Since the model runs for 5 years, this equation does not apply when t=4).

Similarly, for one year Improved fallows, replace CP_t with $SS_{1.t}$ and $CP_{1.t}$ for Sesbania sesban and Pigeon peas, respectively. Also replace M_1C_t,with M_1S_t and M_1P_t for Sesbania sesban and Pigeon peas, respectively.

Accounting Equations for two year Sesbania sesban Improved fallows

The fallows area in year t should be equal to the area planted to maize in year t+1.

Sesbania sesban two year Improved fallows

Equation 60a. $(SS_{2.t})_t - (SS_{2.t})_{t+1} = 0$ for $t = 1,2$

Equation 60b. $(SS_{1.(t-1)})_t - (M_1S_{2.(t-1)})_{t+1} = 0$ for $t = 2,3$

The area planted to maize after the green manure is replanted to maize in year t+3

Equation 60c. $(M_1S_{2.(t-2)})_t - (M_2S_{2.(t-2)})_{t+1} = 0$ for $t = 3,4$

Similarly, for Pigeon pea Two-year Improved fallows, replace $SS_{2.t}$ with $CP_{2.t}$ and $M_2S_{2.t}$ with $M_2P_{2.t}$.

Accounting Equations for three year Sesbania Sesban Improved fallows

The fallows area in year t should be equal to the area planted to maize in year t+1.
Equation 61a. $(SS_{3.t})_t - (SS_{3.t})_{t+1} = 0$ for $t = 1$

Equation 61b. $(SS_{3.(t-1)})_t - (SS_{3.(t-1)})_{t+1} = 0$ for $t = 2$

Equation 61c. $(SS_{t.(t-2)})_t - (M_1S_{2.(t-2)})_{t+1} = 0$ for $t = 3$

The area planted to maize after the green manure is replanted to maize in year t+3

Equation 61d. $(M_1S_{2.(t-3)})_t - (M_2S_{2.(t-3)})_{t+1} = 0$ for $t = 4$

Similarly, for Pigeon pea Three-year Improved fallows, replace $SS_{3.t}$ with $CP_{3.t}$ and $M_2S_{3.t}$ with $M_2P_{3.t}$.

LIST OF REFERENCES

Alvord, E. D. (undated). The Development of Native Agriculture and Land Tenure in Southern Rhodesia. ER&T-224 (11-59) UF Library.

Anand, S. and Sen, A.K., 1996. Sustainable Human Development: Concepts and Priorities. Discussion Paper Number 1. Office of Development Studies. United Nations Development Programme.

Ashley, C. and Carney, D., 1999. Sustainable Livelihoods: Lessons from Early Experience. London. Department of International Development.

Bade, J., Hengsdijk, H., Kruseman, A., Kuyvenhoven, A. and Ruben, R., 1996. The effect of agrarian policy on farm household, welfare and sustainable land use: A modeling exercise. In Ranaweera, N.F.C., Gunasena, H.P.M., and Senayake, Y.D.A. (eds) Changing agricultural opportunities: The role of farming systems approaches. Proceedings of the 14th International Symposium on Sustainable Farming Systems. Pp 393-402. Colombo, Sri Lanka, 11-16 November 1996.

Becker, G.S., 1965. A theory of allocation of time. Economic Journal 75: 493-517.

Blackie, M. J., 1994. Realizing Smallholder Agriculture Potential. In Rukuni, M. and Eicher, C.K. Zimbabwe's Agricultural Revolution. University of Zimbabwe, Harare.

Cabrera, V.E., 1999. Farm problems, solutions and extension programs for small farmers in Canete, Lima, Peru. MS thesis. University of Florida, Gainesville.

Chambers, R. and Conway, G., 1992. "Sustainable rural livelihoods: practical concepts for the 21st century". IDS Discussion Paper 296, Brighton: IDS.

Central Statistical Office, 1998. Statistical Yearbook, Zimbabwe Government, Harare.

Central Statistical Office, 2000. Quarterly Digest of Statistics Yearbook, CSO, Harare.

Chibudu, C., 1998a. Nutrient balances in improved fallows of Sesbania sesban in a maize-based system in sandy soil of Zimbabwe. In Hikwa, D., Maasdorp, B., Mushaka, A., Tapfumaneyi L. and Nyakabau, J. (eds.) Soil Fertility Improvement through Agroforestry in Zimbabwe. Proceedings of the second national agroforestry seminar: 9-10 October 1997. pp 88-92. Zimbabwe Scientific Association, Harare.

Chibudu, C., 1998b. Green manuring crops in a maize-based communal area, Mangwende: Experiences using participatory approaches. In Waddington, S.R., Murwira, H.K., Kumwenda, J.D.T., Hikwa, D. and Tagwira, F. (eds). Soil Fertility Research for Maize-based Farming Systems in Malawi and Zimbabwe. Proceedings of a Soil Fert Net Results and Planning Workshop held from 7-11 July 1997 at Africa University, Mutare, Zimbabwe. pp 87-90. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe 1998,

Chikura, S., 1998. Performance of three leguminous multipurpose perennial trees and shrubs (MPTs) under farmer management in communal areas of Zimbabwe. In Waddington, S.R., Murwira, H.K., Kumwenda, J.D.T., Hikwa, D. and Tagwira, F. (eds). Soil Fertility Research for Maize-based Farming Systems in Malawi and Zimbabwe. Proceedings of a Soil Fert Net Results and Planning Workshop held from 7-11 July 1997 at Africa University, Mutare, Zimbabwe. pp 121-125. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe 1998.

CIMMYT, 1988. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Mexico: CIMMYT Economics Program.

Conway, G., 1997. The Doubly Green Revolution for all in the 21st Century. Ithaca, New York: Comstock Publishing.

De Koejer, T.J., Wossink, G.A.A., van Ittersum, M.K., Struik, P.C. and Renkema, J.A., 1999. A conceptual model for analyzing input-output coefficients in arable farming systems: from diagnosis towards design. Agricultural Systems 61: 31-44.

Dzowela, B.H., 1992. 1991/92 Growing Season Progress Report SADCC/ICRAF Agroforestry Project, Zimbabwe, 49 pp.

Dzowela, B.H., 1993. 1993 Progress Report, ICRAF Project No. CY-R425H-CD1, SADC-ICRAF Agroforestry Project, Zimbabwe.

Eicher C.K. and Kupfuma, B., 1997. In Byelee, D. and Eicher, C.K. (eds.) Africa's Emerging Maize Revolution. pp 25-43. London: Lynne Reinner Publishers.

Ellis, F., 1993. Peasant economics. Cambridge; New York: Cambridge University Press.

Ellis, F., 1992. Agricultural policies in developing countries. Cambridge; New York: Cambridge University Press.

FAO, 2002. FAOSTAT Agriculture Data. http://apps.fao.org/. May 22, 2002.

Farm Management Research Section, 1990. The second Annual Report of Farm Management Data for the Communal Area Farm Units, 1989/90 Farming Season. Harare: Economic and Markets Branch.

Farming Systems Research Unit , 1993. Soil Fertility Management by Small Holder Farmers: A Participatory Rural Appraisal in Chivi and Mangwende Communal Area, Zimbabwe. Department of Research and Specialist Services, Harare.

G-egziabher, A. 1995. Resource Allocation in Small-scale Farming under Risk in Arssie, Ethiopia. Studien zur landlichen entwicklung, 48. Lit Verlag Munster-Hamburg.

Gladwin, C.H., Buhr, K.L., Goldman, A., Heibbsch, Hildebrand, P.E., Kidder, G., Langham, M., Lee, D. Nkedi-Kizza, P., and Williams, D., 1997. Gender and soil fertility in Africa. In Buresh, R.J., Sanchez, P.A. and Colhoum, F. (eds) Replenishing Soil Fertility in Africa. pp 219-236. SSSA Special Publication 51.

Hazell, P.R. and Norton R.D., 1986. Mathematical Programming for Economic Analysis in Agriculture. New York: Macmillan Publishing Company.

Hedden-Dunkhorst, B., 1993. The Contribution of Sorghum and Millet versus Maize to Food-Security in Semi-Arid Zimbabwe. Farming systems and resource economics in the tropics; Vol 15. Wissenschaftsverleg, Vauk Kiel KG.

Hildebrand, P.E., 1986. Perspectives on Farming Systems Research and Extension. Lynne Riener Publishers Inc., Boulder, Colorado.

Hikwa, D. and Waddington, S.R., 1998. Annual legumes for improving soil fertility in the smallholder maize-based systems in Zimbabwe. In Hikwa, D., Maasdorp, B., Mushaka, A., Tapfumaneyi L. and Nyakabau, J. (eds.) Soil Fertility Improvement through Agroforestry in Zimbabwe. Proceedings of the second national agroforestry seminar: 9-10 October 1997. pp 15-26. Zimbabwe Scientific Association, Harare.

Hoekstra, D.A., 1985. The use of economics in diagnosis and design of agroforestry systems. working paper no. 29. Nairobi: ICRAF, 85 pp.

Kamau, I.M., 1989. Agroforestry Potential for the Unimodal Upland Plateau of Zimbabwe. AFRENA. Report series No. 2. ICRAF, Nairobi, 80 pp.

Kwesiga, F.P. Simwanza; R.D. Mwiinga and Phiri, D.M., 1992. Agroforestry Research Project in Eastern Province Zambia.1991 Annual Research Report; AFRENA Report No. 51. ICRAF.

Litow, P.A., 2000. Food Security and Household Livelihood Strategies in the Maya Biosphere Reserve: Importance of Milpa in the Community of Uaxactun, Peten, Guatemala. MS thesis. University of Florida, Gainesville.

Low, A., 1986. Agricultural Development of Southern Africa: Farm-household Economics and Food Crisis. James Currey, London.

Mafongoya, P.L. and Dzowela, B.H., 1999. Biomass production of tree fallows and their residual effect on maize in Zimbabwe. Agroforestry Systems 47: 139-151.

Mafongoya, P.L. and Dzowela, B.H., 1998. Soil fertility replenishment through agroforestry systems in two contrasting agro-ecological zones in Zimbabwe. In Hikwa, D., Maasdorp, B., Mushaka, A., Tapfumaneyi L. and Nyakabau, J. (eds.) Soil Fertility Improvement through Agroforestry in Zimbabwe. Proceedings of the second national agroforestry seminar: 9-10 October 1997. pp 31-42. Zimbabwe Scientific Association, Harare.

Mapfumo, P., 1998. Legumes: An under-utilized resource in communal areas of Zimbabwe. The Zimbabwe Science News, 32.

Mapfumo, P., Mafongoya, P. and Mpepereki, S., 1998. Opportunities for the Introduction of Pigeon peas into Smallholder farming Systems in Zimbabwe. In Hikwa, D., Maasdorp, B., Mushaka, A., Tapfumaneyi L. and Nyakabau, J. (eds.) Soil Fertility Improvement through Agroforestry in Zimbabwe. Proceedings of the second national agroforestry seminar: 9-10 October 1997. pp 60-65. Zimbabwe Scientific Association, Harare.

Muir, K., 1994. Agriculture in Zimbabwe. In Rukuni, M. and Eicher, C.K. Zimbabwe's Agricultural Revolution. Harare: University of Zimbabwe, Harare.

Muza, L., Pashapa, L. and Feresu, S., 1998. Need to revive green manuring in soil fertility management in Zimbabwe, The Zimbabwe Science News, 32.

Nair, P.K.R., 1989. Agroforestry defined. In Nair, P.K.R. (ed) Agroforestry Systems, Kluwer Academic Publishers, The Netherlands

Netting, R. M., 1993. Smallholders, Householders. Stanford University Press, California.

North, D.C., 1991. Institutions. The Journal of Economic Perspectives, 5: 97-112.

Nzuma, J. K., Murwira, H.K. and Mpepereki, S., 1998. Cattle manure management options fro reducing nutrient losses: Household perceptions and solutions in Mangwende, Zimbabwe. In Waddington, S.R.; Murwira, H.K.; Kumwenda J.D.; Hikwa, D. and Tagwira, F. (eds.) Soil Fertility for Maize-Based Systems in Malawi and Zimbabwe. Proceedings of the Soil Fert Net Results and Planning Workshop held from 7 to 11 July 1997 at Africa University, Mutare, Zimbabwe. pp 183-190. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe.

Ostrom, E., 1990. Governing the Commons: The Evolution of Institutions for Collective Action. Cambridge: Cambridge University Press.

Pingali, P. and Binswanger, H.P., 1998. "Population Density and Farming Systems: The Changing Locus of Innovations and Technical Change." In Lee, R.D., Arthur, W.B., Kelly, A.F., Rogers, G. and Srinivasan, T.N. Population, Food and Rural Development. pp 51-76. Oxford: Oxford University Press.

Rondinelli, D.A., 1979. Administration of Integrated Rural Development policy: The Politics of Agrarian reform in Developing Countries. World Politics, 312: 389-416

Rohrbach, D., 1989. The Economics of Smallholder Maize Production in Zimbabwe: Implications for Food security. MSU International Development Paper 11. East Lansing, Michigan: Department of Agricultural Economics, Michigan State University.

Rorhbach, D., 1998. Developing more practical fertility management recommendations. In Waddington, S.R., Murwira, H.K., Kumwenda, J.D.T., Hikwa, D. and Tagwira, F. (eds). Soil Fertility Research for Maize-based Farming Systems in Malawi and Zimbabwe. Proceedings of a Soil Fert Net Results and Planning Workshop held from 7-11 July 1997 at Africa University, Mutare, Zimbabwe. pp 237-244. Soil Fert Net and CIMMYT-Zimbabwe, Harare, Zimbabwe.

Ruben R, Moll, H. and Kuyvenhoven, A., 1998. Integrating Agricultural Research and policy Analysis: Analytical Framework and Policy Applications for Bio-economic modelling. Agricultural Systems. 58: 331-349

Rukuni, M., 1990. The development of Zimbabwe's agriculture: 1890-1990. Working paper AEE 7/90. Department of Agricultural Economics and Extension, University of Zimbabwe, Harare

Ruttan, V.W. and Hayami, Y., 1984. "Induced Innovation Model of Agricultural Development." In Eicher, C.K. and Staatz, J.M. (eds) Agricultural Development in the Third World. pp 59-74. Baltimore: John Hopkins University Press.

Sanchez, P.A., 1999. Improved fallows come of age in the tropics. Agroforestry Systems 47: 3-12.

Schultz, T.W., 1964. Transforming Traditional Agriculture. New Haven: Yale University Press.

Scoones, I., 1998. Sustainable Rural Livelihoods: A framework for analysis. IDS Working Paper 72. Institute of Development Studies.

Sen, A., 1985. The Standard of Living. Cambridge: Cambridge University Press.

Sicular, T., 1986. Using a Farm Household Model to Analyze Labor Allocation on a Chinese Collective Farm. In Singh, I, Squire, L and Strauss J., (eds) Agricultural Household Models: Extensions Applications and Policy. pp 277-305. World Bank, Washington.

Singh, I. and Subramanian, J., 1986. Agricultural Household Modeling in a Multi crop Environment: Cases Studies in Korea and Nigeria. In Singh, I., Squire, L. and Strauss, J., (eds.) Agricultural Household Models: Extensions Applications and Policy. pp 95-115. Baltimore: John Hopkins University Press.

Singh, I., Squire, L. and Strauss, J., (eds.) 1986. Agricultural Household Models: Extension, Applications and Policy. Baltimore: John Hopkins University Press.

Sullivan, A.J., 2000. Decoding diversity: Strategies to Mitigate Household Stress. MS thesis. University of Florida, Gainesville.

Thomson, A. M., 1988. Zimbabwe. In Harvey, C. (ed), Agricultural Pricing Policy in Africa. pp 186-221. New York: MacMillian Publishers.

Thomson, A. M and Metz, M., 1997. Implications of Economic Policy for Food Security: A Training Manual. FAO. Rome.

Thorner, D., Kerbley, B. and Smith, R.E.F., 1986. Chayanov A. V. on the Theory of the Peasant Economy. Madison, Wisconsin, University of Wisconsin Press.

Tibaijuka, A., 1994. The Costs of Differential Gender Roles in African Agriculture: A Case Study of Smallholder Banana-coffee Farms in the Kagera Region, Tanzania. Journal of Agricultural Economics. 45: 69-81.

Timmer,C.P., Falcon W.P. and Pearson S.R., 1983. Food Policy Analysis. Baltimore: The John Hopkins University Press.

Tomich, T.P., Kilby, P. and Johnson, B.F. 1995. Transforming Agrarian Economies. Ithaca: Cornell University Press.

UNDP, 2000. Sustainable Livelihoods: Building on the Wealth of the Poor. http://www.undp.org/sl/. August 10, 2000.

Wivstad, M., 1997. Green manuring crops as a source of nitrogen in cropping systems. Doctoral thesis. Uppsala: Swedish University of Agricultural Science.

Wolmer, W., 1997. Crop-livestock integration: the dynamics of intensification in contrasting agroecological zones: a review. Brighton, UK: Institute of Development Studies.

BIOGRAPHICAL SKETCH

Maxwell Mudhara was born in Makoni District, in the east of Zimbabwe. He studied for a BSc. Agriculture degree, majoring in agricultural economics, between 1983 and 1985 at the University of Zimbabwe. After briefly working for the government Central Statistical Office, in 1988 he was awarded a CIMMYT fellowship to study for a master's degree at the University of Zimbabwe. On completing the master's degree in 1989, he rejoined government as a researcher in the Department of Research and Specialist Services of the Ministry of Agriculture, where he conducted adaptive research on smallholder farms. Through his interest in the improvement of the living standards of the smallholder farmers, he was awarded a W. K. Kellogg Foundation International Study Grant Fellowship to study for a PhD. In the spring of 1998, he joined the PhD program in the Department of Food and Resource Economics at the University of Florida, Gainesville. Maxwell expects to be awarded a Doctor of Philosophy degree in the field of agricultural development in August 2002. Maxwell is married to Emma and has two sons, Julian and Takudzwa.

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Peter H. Hildebrand, Chair
Professor of Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Chris O. Andrew
Professor of Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Christina H Gladwin

Christina Gladwin.
Professor of Food and Resource Economics

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

P.K. Nair
Distinguished Professor of Forest Resources and Conservation

This dissertation was submitted to the Graduate Faculty of the College of Agricultural and Life Sciences and to the Graduate School and was accepted as partial fulfillment of the requirements for the degree of Doctor of Philosophy.

August 2002

Jimmy G. Cheek

Dean, College of Agricultural and Life Sciences

Dean, Graduate School